NEW

INSIDE HISTORY COLLECTION

SCIENTIFIC *pioneers*

The greatest geniuses and their discoveries that changed the world

£9.99

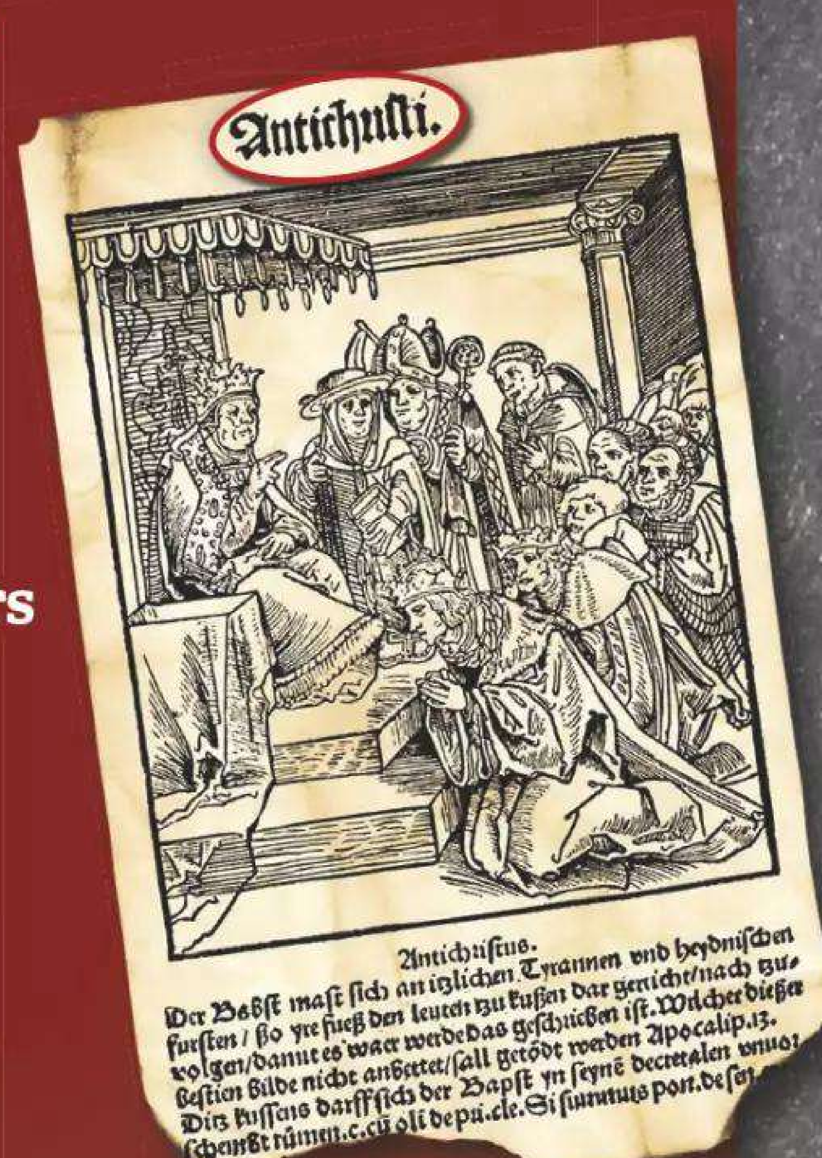
Scientific journeys of discovery

At the end of the 18th century, the world entered a new era. Within a few short years, inventors and scientists tamed the immense power of electricity, mapped the history of human evolution and solved the greatest mysteries of the universe.
It was preceded by 500 golden years in which alchemists, astronomers and the greatest genius in history laid solid foundations by studying the solar system, understanding the secrets of elements and creating groundbreaking inventions. Now their knowledge was transporting the world towards better times. Suddenly, doctors could see bacteria swarming under the microscope and understand the origins of disease, while innovative engineers threw themselves into saving the world. Sewers were dug under Europe's cities, water was harnessed to create untold wealth, culminating in the construction of the Empire State Building, the tallest building the world had yet seen, which shot up in record time.
Take a journey of discovery with the pioneers of science and learn about their incredible achievements.

Enjoy the issue!

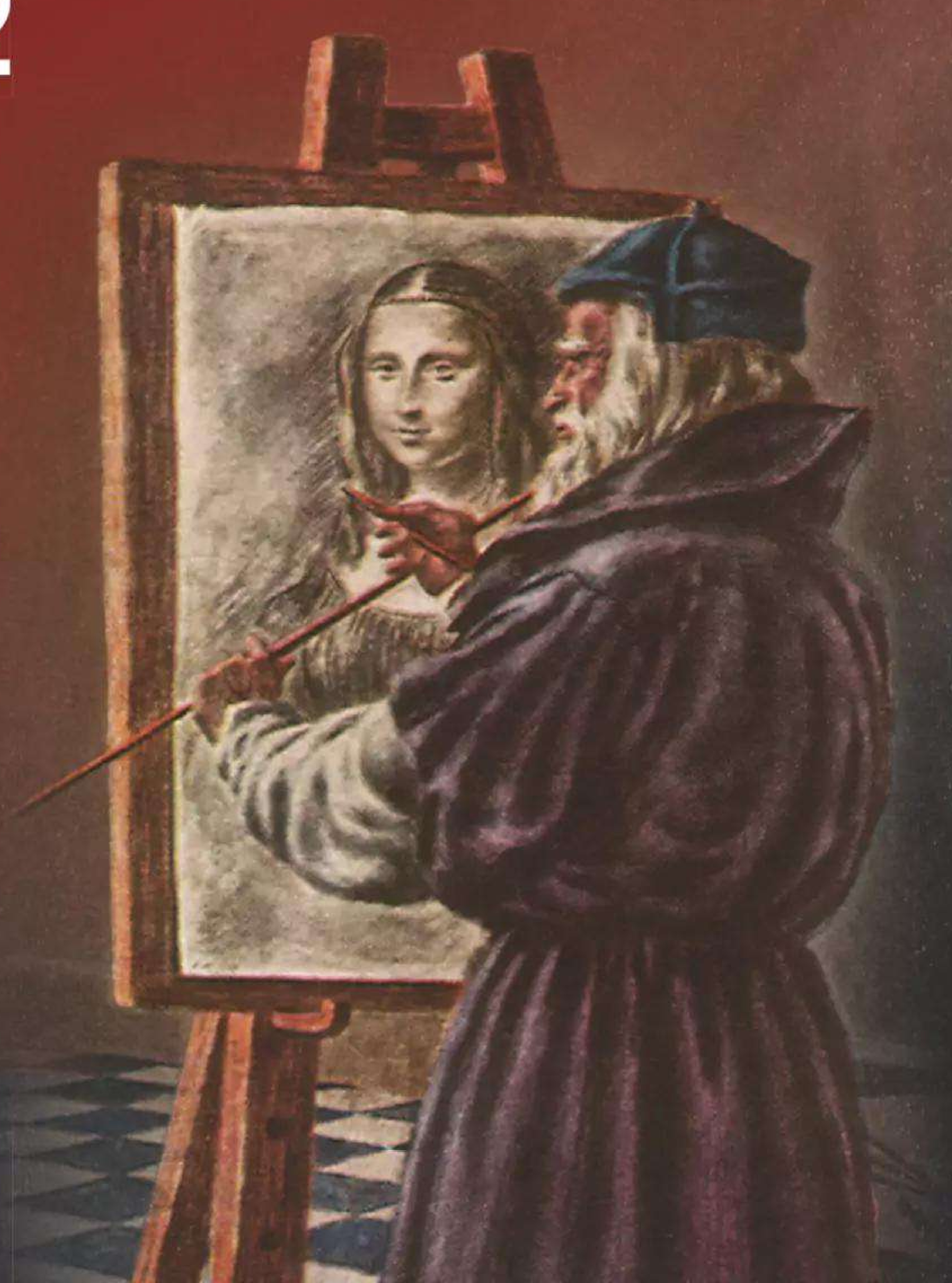
The first scientists

Alchemists, astronomers and the greatest genius in history drove the world forward from the 14th century. By mapping the solar system, uncovering the secrets of the elements and creating groundbreaking inventions, they delivered the world into a new age and better times.



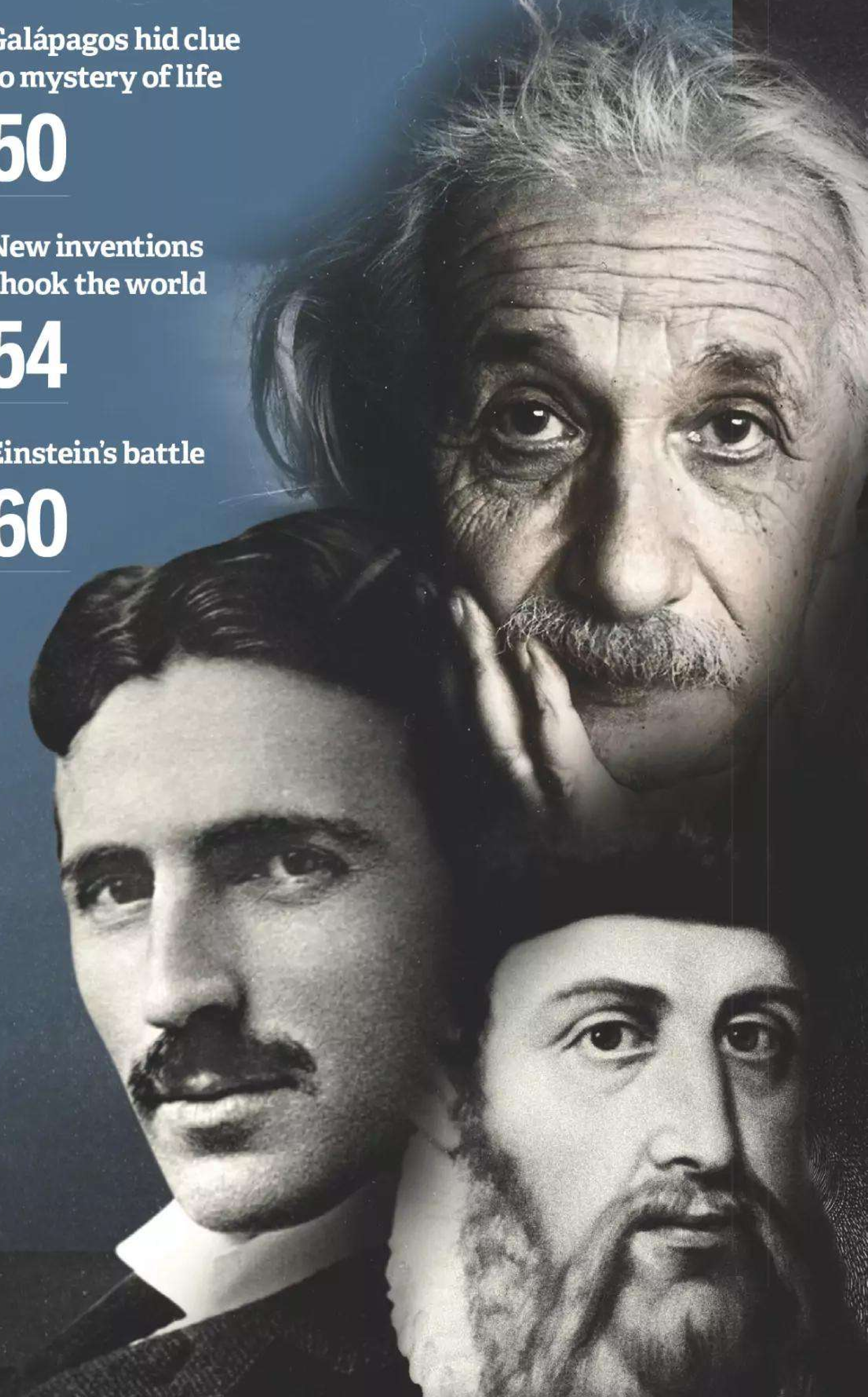
Antichristus.

Antichristus.
Der Babst maßt sich an itzlichen Tyrannen und heydnischen fursten / ßo yre fueß den leuten zu kussen dar gereicht/nach zu volgen/damit es war werde das geschrieben ist. Welcher dießer bestien bilde nicht anbetet/sall getödt werden Apocalip.13. Diß kussens darff sich der Bapst yn seynē decretalen unvor schempt rümen. c. cu oli de pri. cle. Si summus pont. de sen



The age of invention

At the end of the 18th century, the world entered a new era. Inventors and scientists harnessed the immense power of electricity, described the history of human evolution and solved the greatest mysteries of the universe. Read about their achievements.

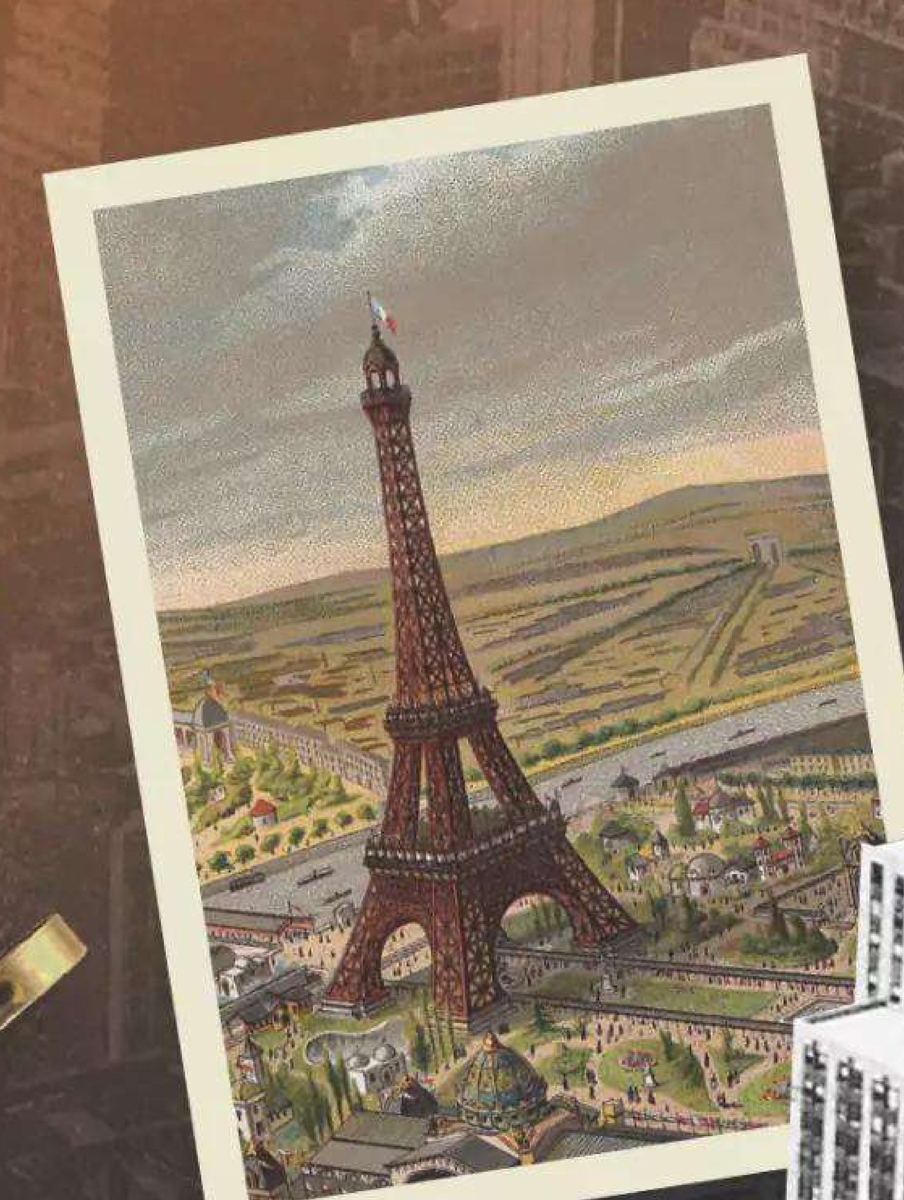


The dawn of modern medicine

By keenly studying corpses and improving glass lenses, doctors were able to understand human anatomy and the origins of disease. Suddenly, they could see bacteria swarming under the microscope, improve surgery and understand how vaccination could save millions of lives.

Incredible engineering achievements

Brave and innovative engineers were behind the most incredible feats of the 20th century. Sewer systems were dug under Europe's major cities, while water was harnessed to create untold wealth. It all culminated in the erection of the Empire State Building, which shot to the top in record time against all odds.



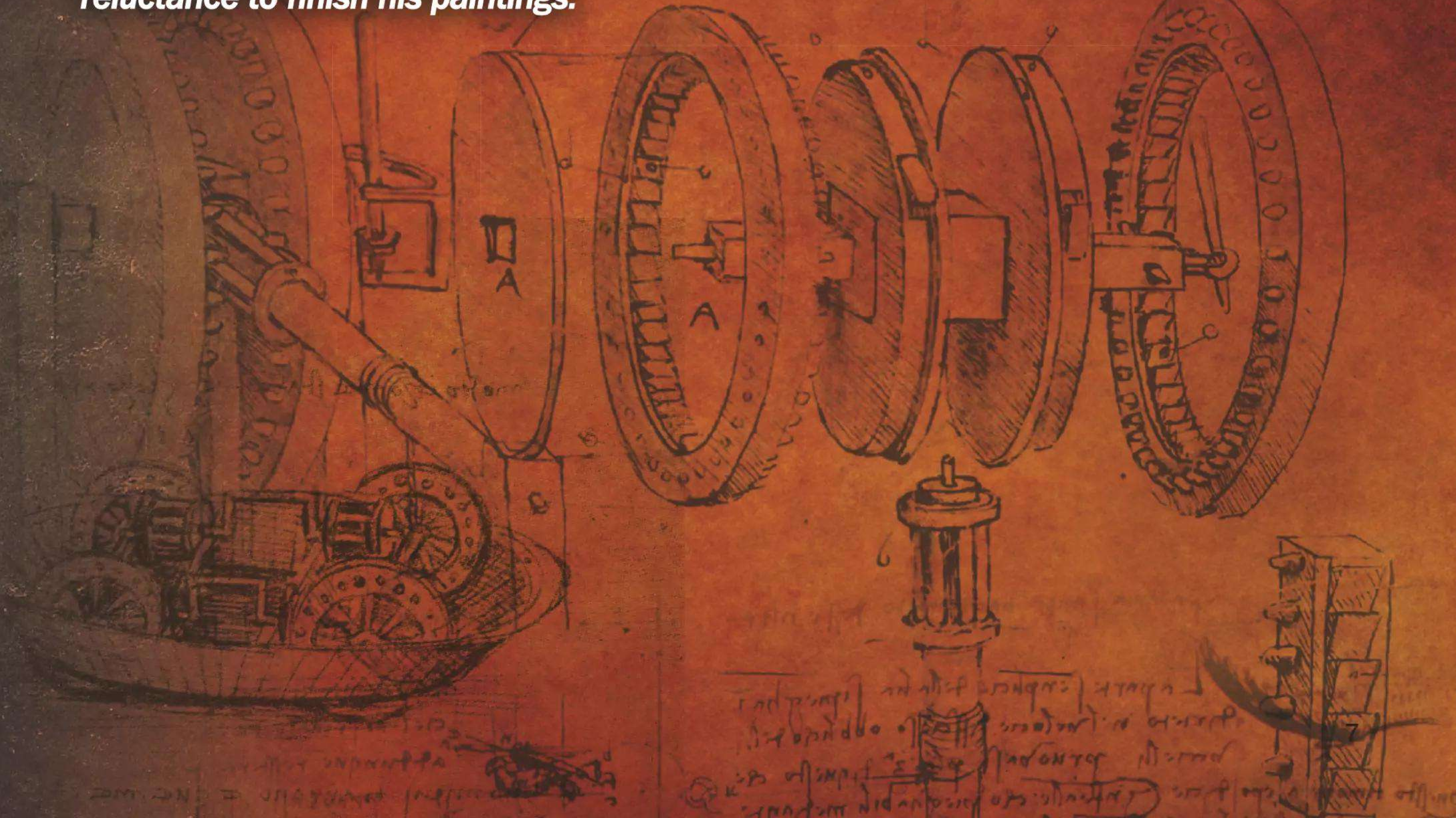
Leonardo da Vinci was one of the most skilful painters of the Renaissance.
GETTY IMAGES & SHUTTERSTOCK

ITALY/1452

In the 15th century, Italy was divided into a series of city-states vying to be the leading power on the boot-shaped peninsula – a power struggle in which the neighbouring French kingdom was also involved.

Leonardo's talent was wasted

Painting was the albatross that hung around Leonardo da Vinci's neck. The universal genius never really made it as an engineer, scientist and inventor, because his fame as an artist clung to him – despite his reluctance to finish his paintings.



BY THERESE BOISEN HAAS & ANDREAS ABILDGAARD

Happiness turned out to be a horse. And it came into Leonardo da Vinci's life in the spring of 1489 when the Duke of Milan, Ludovico Sforza, commissioned an impressive equestrian statue of his father to remind the city's residents of the greatness of the Sforza family.

An inspired Leonardo set to work: his statue would be eight metres high and cast from 75 tonnes of bronze. First, however, he decided to thoroughly study the horse's anatomy so that the statue would be as lifelike and convincing as possible.

Leonardo dissected horses, took precise measurements and drew diagrams showing horse bones in proportion. He found his subject so intriguing that Leonardo decided to write a thesis on horse anatomy. But it was never finished, because along the way Leonardo was distracted by coming up with a method to create cleaner stables using water sluices and recesses in the floors. He also devised a mechanism to fill the feeding troughs via pipes from the ceiling.

In the middle of his work, Leonardo suddenly realised that the duke was looking for a new artist for the job – Ludovico Sforza was tired of waiting. Under such pressure, Leonardo – after a few years' delay – started moulding a clay model for the bronze statue in his studio.

BRIDGEMAN IMAGES

Da Vinci's greatest rival was the artist Michelangelo. While the tall, handsome Leonardo wore pink robes, his rival often wore more muted colours.

Florence's geniuses hated each other

Throughout his life, Leonardo da Vinci had artistic rivals. When he returned to Florence from Milan in 1503 at the age of 51, Leonardo realised that in his absence, 28-year-old artist Michelangelo had become the city's new star.

While Leonardo was charming, mild-mannered and always surrounded by friends and admirers, Michelangelo was a neurotic,introverted loner who easily fell out with others. Leonardo disliked his younger competitor:

"You would think you were looking at a sack of walnuts rather than the human form," he said, inferring that Michelangelo painted like a sculptor. He patronisingly called him "the anatomical painter".

When the city council set up a committee to decide where Michelangelo's five-metre-high marble statue of the naked David should be placed, Leonardo recommended placing it in a secluded colonnade.

Insatiable curiosity drove his work

Leonardo da Vinci must have been the most curious man in the history of the world, with almost any subject interesting him. Again and again, the Italian was overcome by a thirst for knowledge – making it difficult for him to concentrate on a single field at a time. But curiosity was also the driving force behind Leonardo's genius, even in childhood when he was given the right conditions to fulfil it.

Leonardo was born as the result of an affair between notary Piero da Vinci and a peasant girl in the village of Vinci, where the family estate was located.

In the spring of 1452, 15-year-old Caterina Lippi gave birth to her and Piero's son. As an illegitimate child, Leonardo did not have to be trained for a career as a notary – a profession that had been handed down to the first-born legitimate son in the da Vinci family for generations. Piero, who lived in the city of Florence, about 25 kilometres from Vinci, acknowledged the child but had no intention of marrying the young girl. He was engaged to a suitable lady from a wealthy family, and they married later that year.

Leonardo spent his early years living with his mother, whom the da Vinci family married to a local labourer. Leonardo soon had half-siblings, and as the children grew in the small home, he spent more and more time with his paternal grandfather, with whom he moved in when he was five years old.

From the da Vinci estate, he roamed the beautiful Tuscan countryside, where he found fossils in mountain caves and intriguing plants in the meadows, which he brought home to sketch.

> **"They strut about ... not with their own labours, but by those of others."**
>
> Leonardo da Vinci on the scholars of his time.

Happy childhood with no schooling

Piero da Vinci didn't spend money to send his illegitimate son to one of the "Latin schools", where wealthy Renaissance families had their children educated in ancient languages and culture. Leonardo was spared dusty textbooks and being taught to respect authority.

Instead, he learnt from his own observations in nature, puzzling over hundreds of phenomena that no one else wondered about. Why was the sky blue, how do birds fly, and what causes water to swirl as it travels downriver?

Later in life, he was even proud of his lack of schooling and mocked those who might look down on him because of it. "They strut about puffed up and pompous, decked out and adorned not with their own labours, but by those of others," he wrote in a notebook.

However, near-contemporary Italian writer Giorgio Vasari recorded that Leonardo struggled to catch up on his schooling as an adult. He threw ▶

Ideas poured out of Leonardo da Vinci

A diving suit, a hang-glider and an odometer – Leonardo left behind hundreds of designs for ingenious machines and devices. Few of them were realised in his lifetime.

NIELS-PETER GRANZOW BUSCH/HISTORIE MAGAZINE

HANG-GLIDER

The Italian inventor developed a concept for a hang-glider. Leonardo found inspiration from bird and bat wings. With a few minor adjustments, the glider could probably have worked in practice.

CANNON BATTERY

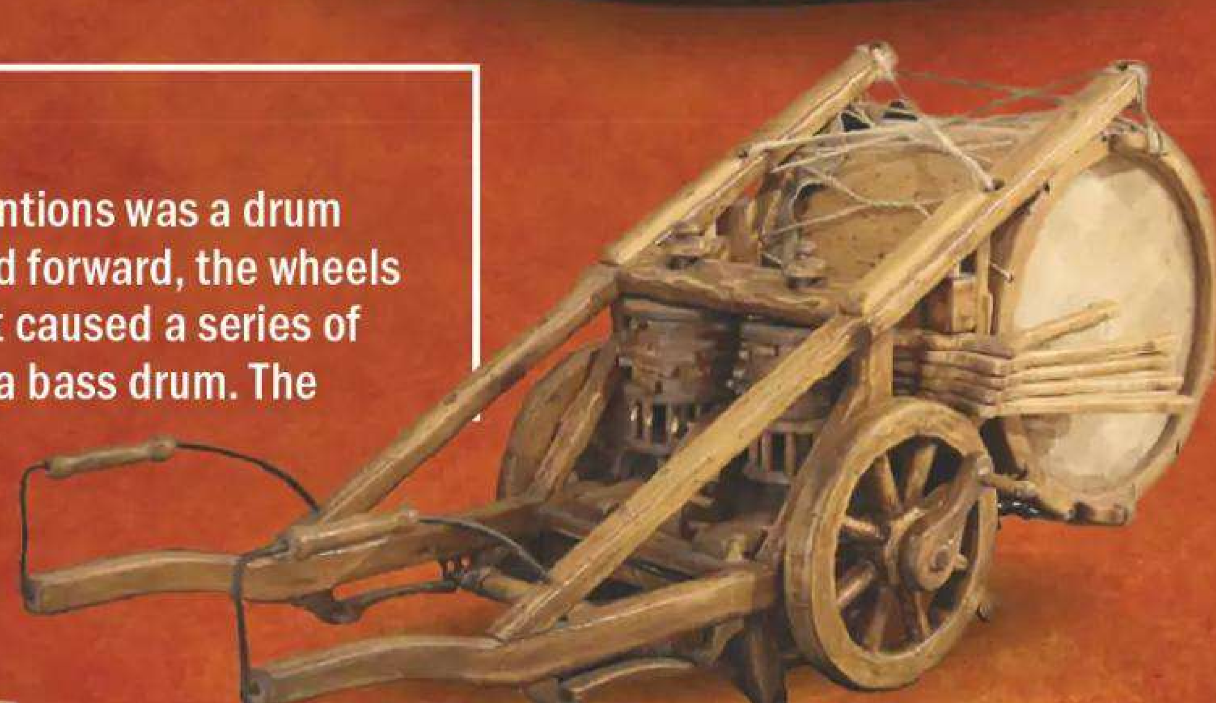
One of da Vinci's more bellicose ideas was a circular device with 16 fixed cannons. In the centre he would place a mechanical device with gears, but its purpose was unclear. Based on the sketch, researchers surmise that oars were to be attached so that the weapon could be manoeuvred at sea.

DIVING SUIT

Leonardo envisioned a suit in which the diver breathed oxygen through hollow sticks or leather tubes floating on the surface of the water. In some versions, he added a urine bag so that the diver could spend hours underwater.

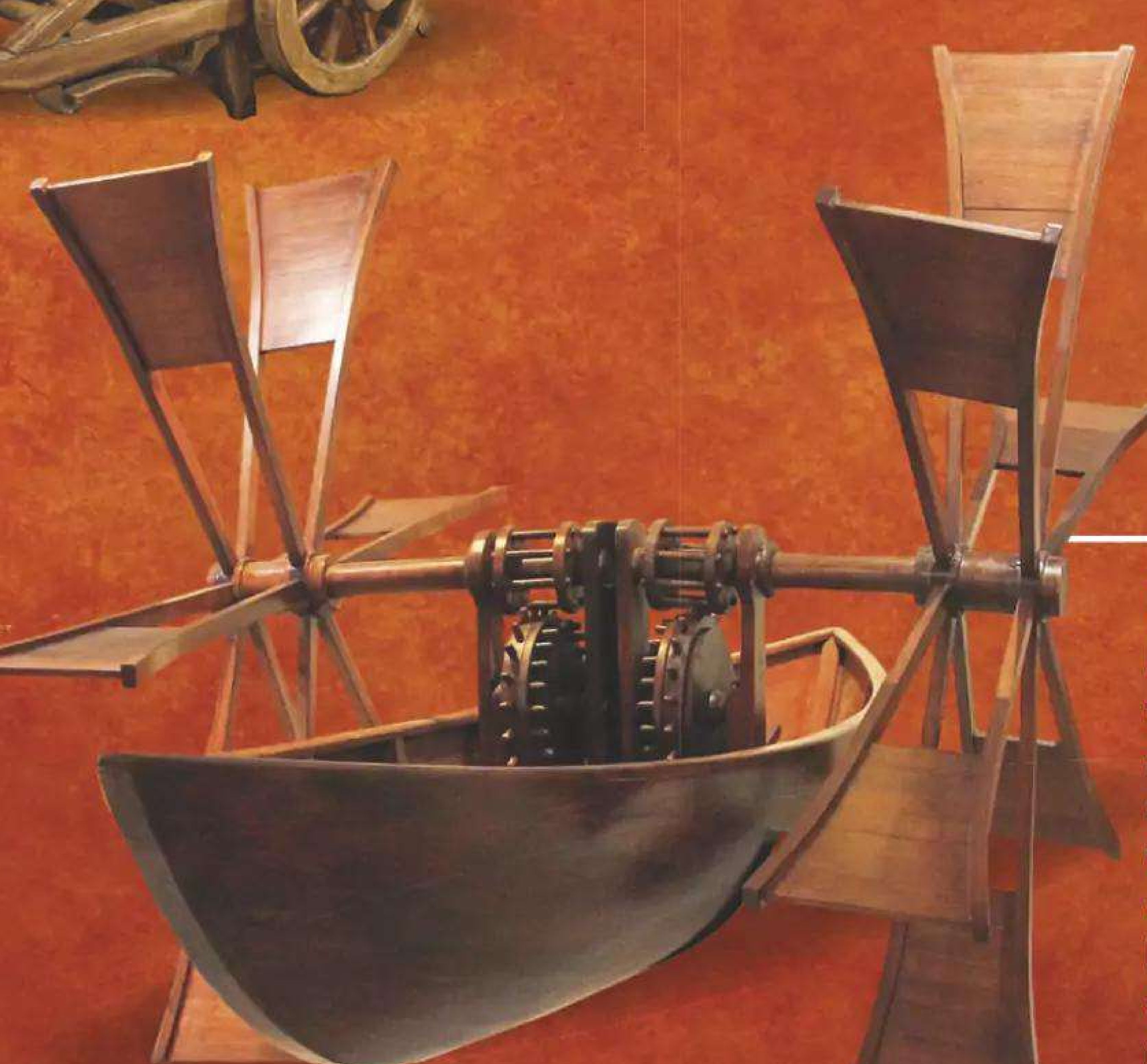
DRUM MACHINE

One of his more festive inventions was a drum machine. When it was pulled forward, the wheels activated a mechanism that caused a series of drumsticks to beat against a bass drum. The machine could be used for parades, for example.



ODOMETER

One of the few inventions Leonardo built and tested was his distance measurer. The machine resembled a wheelbarrow and every time its wheels turned a full revolution, a mechanism dropped a small stone into the box. The number of stones recorded the distance travelled.



PADDLE STEAMER

In trying to create a boat that was easy to sail on calm rivers and canals, da Vinci developed a boat with a type of paddle wheel. According to his drawings, the paddles were to be driven either by hand via a crank handle or by means of fixed foot pedals.

himself into learning Latin, geometry and maths, among other subjects.

In the few months that Leonardo studied arithmetic, for example, he made such enormous progress, according to Vasari, that his teacher was left speechless. Leonardo was clearly not lacking in ability, and his desire for knowledge was already present when he was growing up with his grandparents.

However, everything changed for the young boy when his father's wife died in childbirth. This happened around the same time that the head of the da Vinci family, Leonardo's grandfather, also passed away. Leonardo was still Piero's only child, and at the age of 12, he was now called to Florence to live with his father.

The most glorious city in the world

After arriving in Florence in 1464, Piero da Vinci realised that his gentle son never seemed to stop drawing and making figures. There was no notary buried within him.

Luckily for a creative talent like Leonardo, Florence was rich in opportunities for fulfilment. The city was teeming with silk weavers, goldsmiths, jewellers and painters. The city had about 40,000 inhabitants with at least 100 rich families and a large, affluent middle class. The real ruler of the city, the banker Cosimo de' Medici, had just died and was succeeded by his son Lorenzo de' Medici, who supported the arts and sciences even more than his father. He established academies and gave work to the many philosophers and artists that the city attracted.

In the piazzas of Florence, painters, wood carvers and silk weavers gathered in spare moments to engage in philosophical and scientific discussions. Lorenzo also regularly spoiled the city with grandiose parties and plays – all of which inspired the young Leonardo.

Piero saw where his son was headed, so he gathered some of the boy's best drawings and showed them to his client Andrea del Verrocchio, who ran one of the city's best bottegas – a workshop where all kinds of handicrafts were produced.

Would it benefit his son to study drawing, he asked Verrocchio, who held up the brilliant drawings in front of him, stunned. Leonardo immediately got an apprenticeship with Verrocchio. Here he was taught anatomy, mechanics, drawing techniques and the effects of light and shadow.

Together with the other apprentices, Leonardo produced images of saints to be sold in the bottega's shop.

> **"A beauty of body beyond description, a splendour that rejoiced the most sorrowful souls."**
>
> Description of Leonardo's physical appearance.

Leonardo preferred men

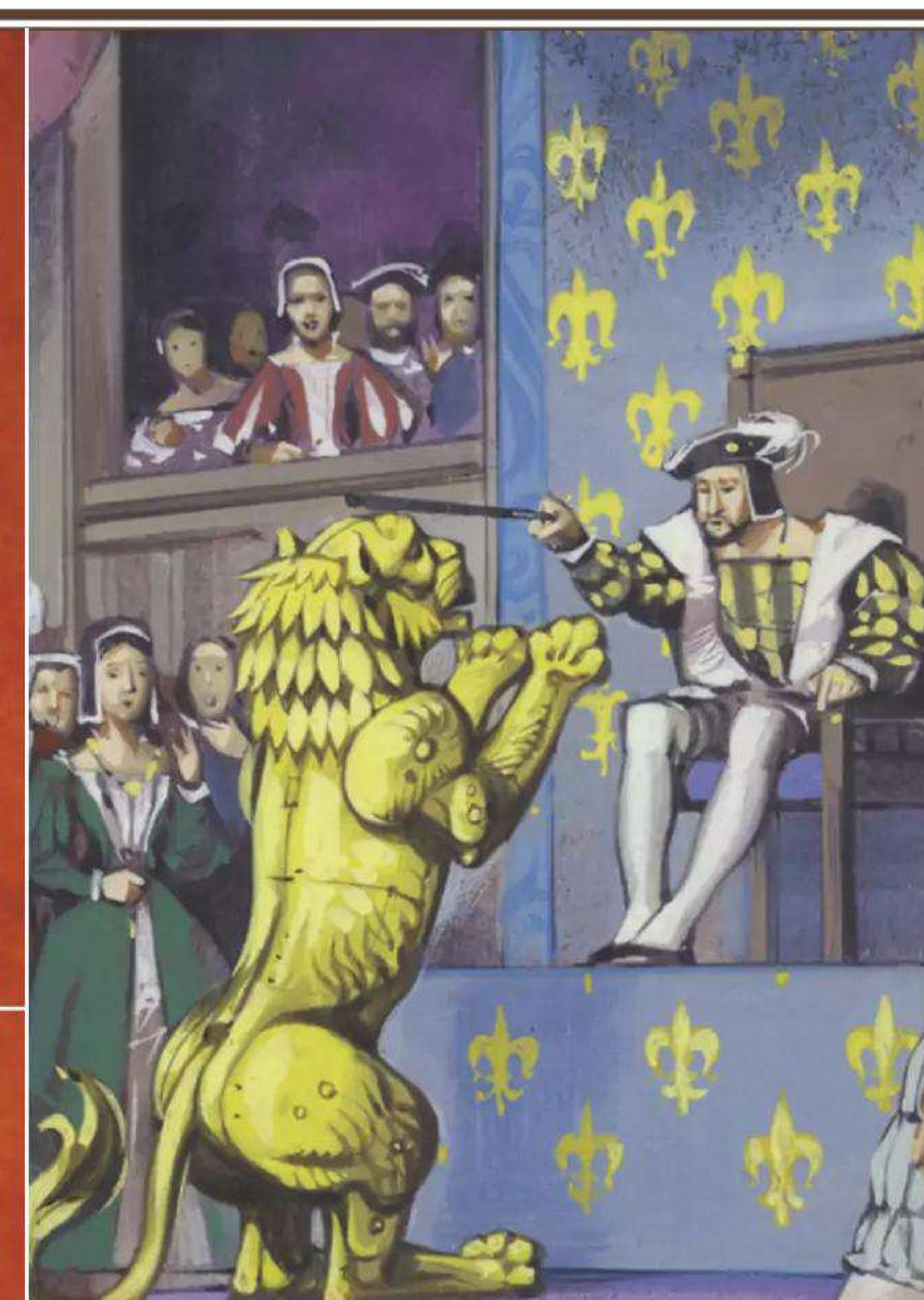
According to author Giorgio Vasari, young Leonardo was muscular with "a beauty of body beyond description, a splendour that rejoiced the most sorrowful souls".

The young rising star was left-handed and wrote in the opposite direction to everyone else, forcing the boy to develop a kind of mirror writing that would eventually fill hundreds of notebooks. On

Rulers gave the people spectacular entertainment

A superb sense of mechanics, light and colour – combined with technical ingenuity and a good dose of imagination – made Leonardo a born director.

The wealthy Medici family in Florence and the Duke of Milan, Ludovico Sforza, encouraged Leonardo to stage spectacular pageants to delight and entertain the masses. Performances were filled with lavish costumes, elaborate backdrops and machines that could rotate scenery or make actors float across the stage. Unlike his many unfinished paintings, Leonardo was forced to meet deadlines when he was hired for a pageant.



Louis XII arrived in Milan after the French conquest of the city. Here he was greeted by Leonardo's lion.

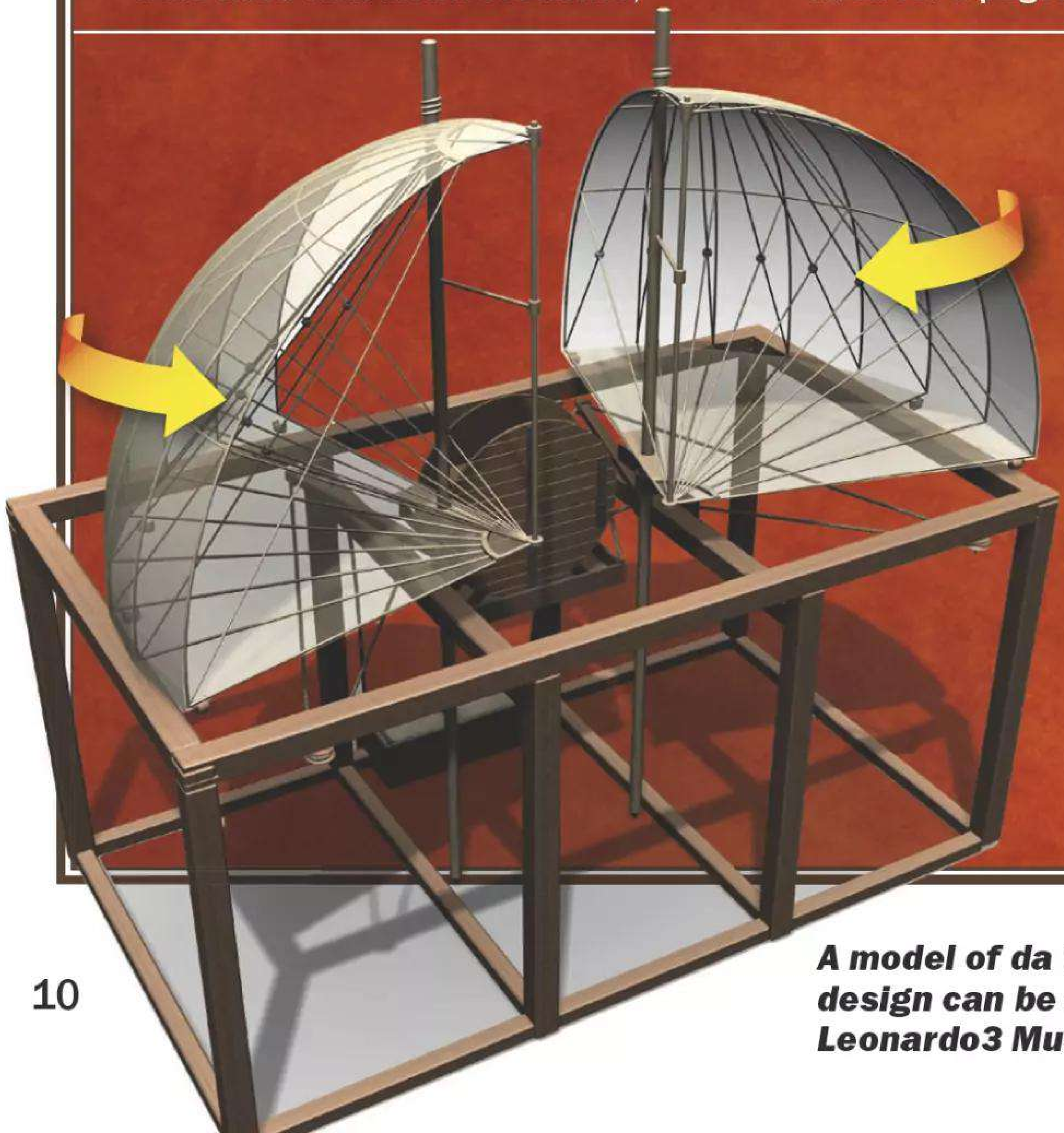
Mechanical lion welcomed king

During Louis XII's visit to Milan in 1509, the French king was greeted by a mechanical lion designed by Leonardo. Apparently, it could open a treasure chest with its paw and pull out bluish baubles filled with golden lilies.

Quick scene change

For one pageant, Leonardo had to show the god Pluto's home in the underworld. The solution was a quarter-spherical backdrop shaped like a mountain and placed on separate turntables.

By rotating the turntables, Leonardo was able to reveal the interior of the mountain, where devils played on pots and created an infernal noise, while blazing fires of different colours lit up the scene.



A model of da Vinci's stage design can be seen today at the Leonardo3 Museum in Milan.

top of that, Leonardo was a vegetarian, dressed in unusual clothes and was homosexual.

For all its liberalism, Florence forbade same-sex relationships, but like many of his fellow artists, Leonardo took the prohibition lightly. In 1476, along with four other young men, he was accused of having sexual relations with a goldsmith's apprentice who, according to the anonymous accusation, "is party to many wretched affairs, and consents to please those persons who request such wickedness of him".

An investigation was launched, but as one of the other accused had married into the prestigious Medici family, the case quietly went away. Leonardo was 24 years old when he left the bottega.

Painter made it big as party organiser

Leonardo's own business was struggling. Of the three commissions he received during his five years as an independent painter in Florence, he started only two.

One of them, entitled *St Jerome in the Desert*, was kept for years so he could work on it from time to time. However, Leonardo's perfectionism led him to give up on completing the painting, and in his notebooks he indulged in pessimism. "Tell me if anything was ever done… Tell me… Tell me," he wrote in despair.

Meanwhile, his rivals enjoyed great success: the painter Botticelli, who had no problem completing his works, was a favourite of the Medici family and received countless commissions. Along with other selected artists, Botticelli was sent to Rome to decorate the Sistine Chapel in the Vatican, as the Medicis often used their Florentine art stars to win allies in the ever-volatile political city-state landscape.

Leonardo had never kowtowed to the Medici family, who only gave him the task of staging the city's pageants – a field in which he had unrivalled skills and was able to stay on schedule.

By the time Leonardo turned 30, he had earned a reputation as a skilful painter who never finished his work. Leonardo himself felt worn out and depressed. He no longer felt that Florence was the place for him. The solution came in 1482 when the Medicis decided to send Leonardo to the neighbouring city of Milan.

War machines secured new job

Leonardo soon set off, taking with him a homemade silver lyre that he'd taught himself to play. He also took his young companion, Atalante, and a wheeled machine he'd constructed to measure distance by counting the revolutions of a wagon wheel. It was 290 kilometres from Florence to Milan, he wrote in his notebook on arrival after a week's journey.

Leonardo was officially sent on a diplomatic mission to entertain the strong and cynical ruler of Milan, Ludovico Sforza, with whom the Medicis wanted to be on good terms.

However, the genius da Vinci privately harboured ambitions to make the prince his new patron. In a long letter, which he wrote on his way to Milan, Leonardo listed in 10 points a number of fantastic weapons and machines that he could build for Duke Sforza. Finally, he briefly mentioned his artistic abilities: "Also, I can execute sculpture in marble, bronze and clay. Likewise in painting, I can do everything possible, as well as any other man, whosoever he may be."

Career change ended in failure

When Leonardo played down his ▶

In 1956, the Mona Lisa was vandalised twice at the Louvre Museum in Paris. First, a visitor poured acid on the painting, then later that year, another visitor threw a stone at it.

IMAGESELECT

Did you know that...

...da Vinci's famous *Mona Lisa* masterpiece was painted on a poplar wood panel? Canvases had been available to artists since the 14th century, but many Renaissance painters favoured wood for their smaller works.

...Italy's National Committee for Cultural Heritage announced in 2010 that an examination of the famous work revealed that the initials LV – Leonardo da Vinci – were carved into Mona Lisa's right eye?

...when Jackie Kennedy asked if the painting could visit the United States, French President de Gaulle said yes? The *Mona Lisa* was shipped from the Louvre in Paris and exhibited at the National Gallery of Art in Washington, DC, and then at The Metropolitan Museum of Art in New York.

...painter Pablo Picasso came under suspicion when the painting was stolen from the Louvre in 1911? However, Picasso turned out to be innocent.

artistic skills, it was partly because the idea of painting was far from his mind and partly because he increasingly saw himself as an inventor and engineer. By boasting about his skills as a weapons designer – even though he had never been near a battlefield – Leonardo was trying to fulfil what he thought Ludovico Sforza wanted most of all: military superiority.

Milan was not a merchant republic like Florence, but a militaristic city-state where its ruling Sforza family had overthrown the previous ducal family. The Sforzas ruled from castles filled with courtiers, officials, astrologers, artists, musicians, animal tamers, actors and jugglers.

The statue never materialised, but Leonardo did produce a gigantic clay model.

Leonardo's horse statue.

The city had about three times more inhabitants than Florence and a university that, in science and intellect, elevated Milan to the level of Bologna, the leading university city of the time.

Leonardo was eager to stay in the city and worked hard to impress Duke Sforza. In a short time, he drew over 30 sketches for new deadly war machines and weapons. Several of his ideas were way ahead of their time – including a tank and a precursor to the machine gun. However, none of these proposals materialised. Ludovico Sforza was so heavily entrenched in the region that he had no need to wage war.

Instead, the duke wanted entertainment, and the prince knew that his new guest was a brilliant theatre director. Soon Leonardo da Vinci was put in charge of organising theatrical performances – just as he'd done in Florence.

Equestrian statue was built in clay

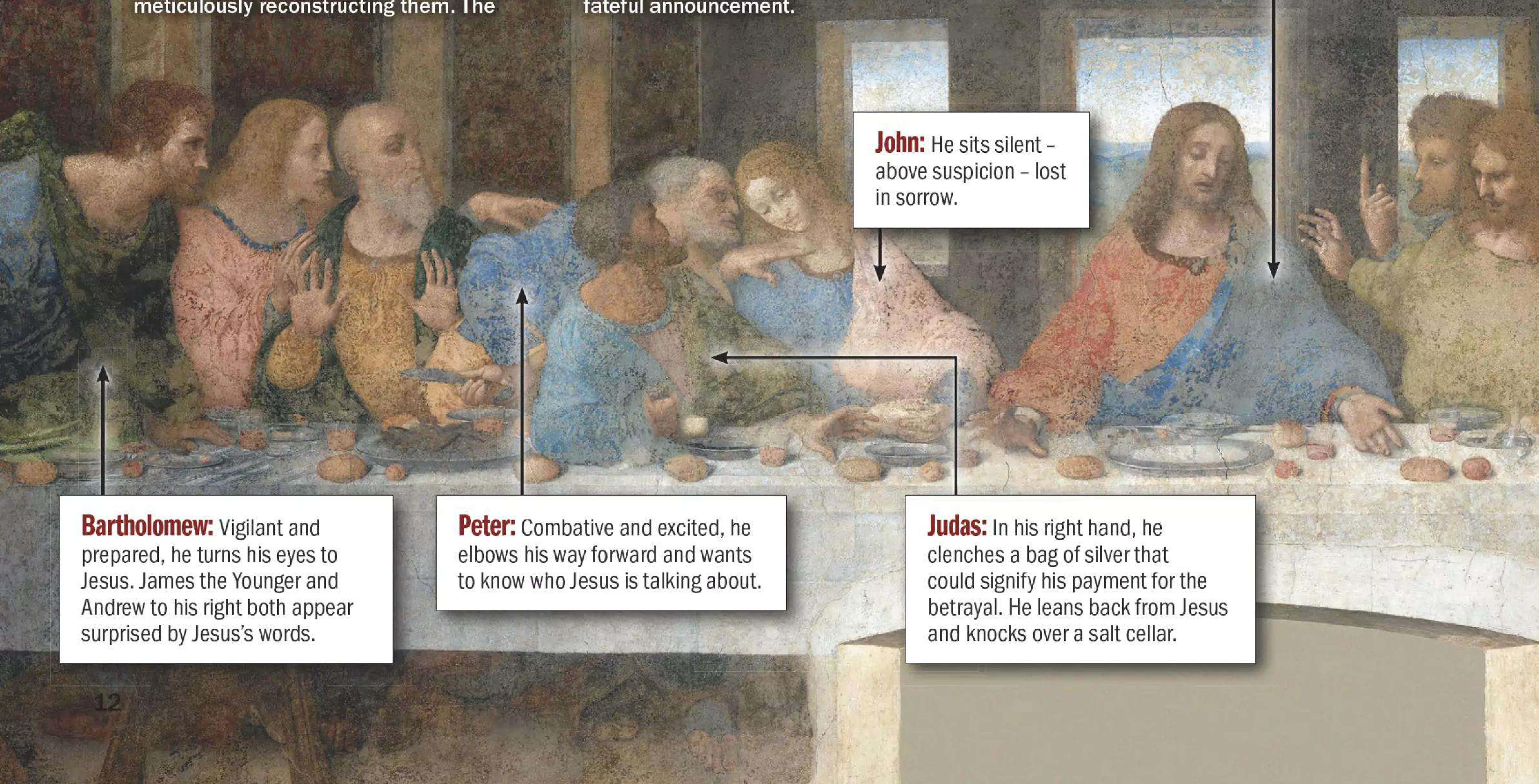
Leonardo's stay in Milan would last 17 years. During that time, he was surrounded by a crowd of students, friends and lovers – just as in Florence. Over the years, he also acquired assistants who had plenty to do in the master's busy workshop. In addition to

The Last Supper made Leonardo famous

Leonardo's patron Ludovico Sforza, the Duke of Milan, wanted a mausoleum. Leonardo was commissioned to decorate it with the most popular religious motif of the time: *The Last Supper*.

The fact that Leonardo's painting *The Last Supper* can still be seen today is due to the restoration that a team of conservators began in 1978. The work took 21 years, and the experts used infrared light to find the original parts of the painting before meticulously reconstructing them. The painting depicts a scene during Jesus's last supper with his 12 disciples. The time is set just after Jesus has spoken the prophetic words, "One of you will betray me."

As a snapshot, Leonardo da Vinci showed the disciples' spontaneous reactions to the fateful announcement.



pageants and painting, Leonardo was involved in many other projects: he designed musical instruments and drafted a new city plan to solve the problems of Milan's overcrowding and waste – this probably could have prevented the plague epidemics that later struck the city.

He also drew caricatures of people he met on the street, wrote fables and started writing a bestiary, the medieval equivalent of a natural history handbook.

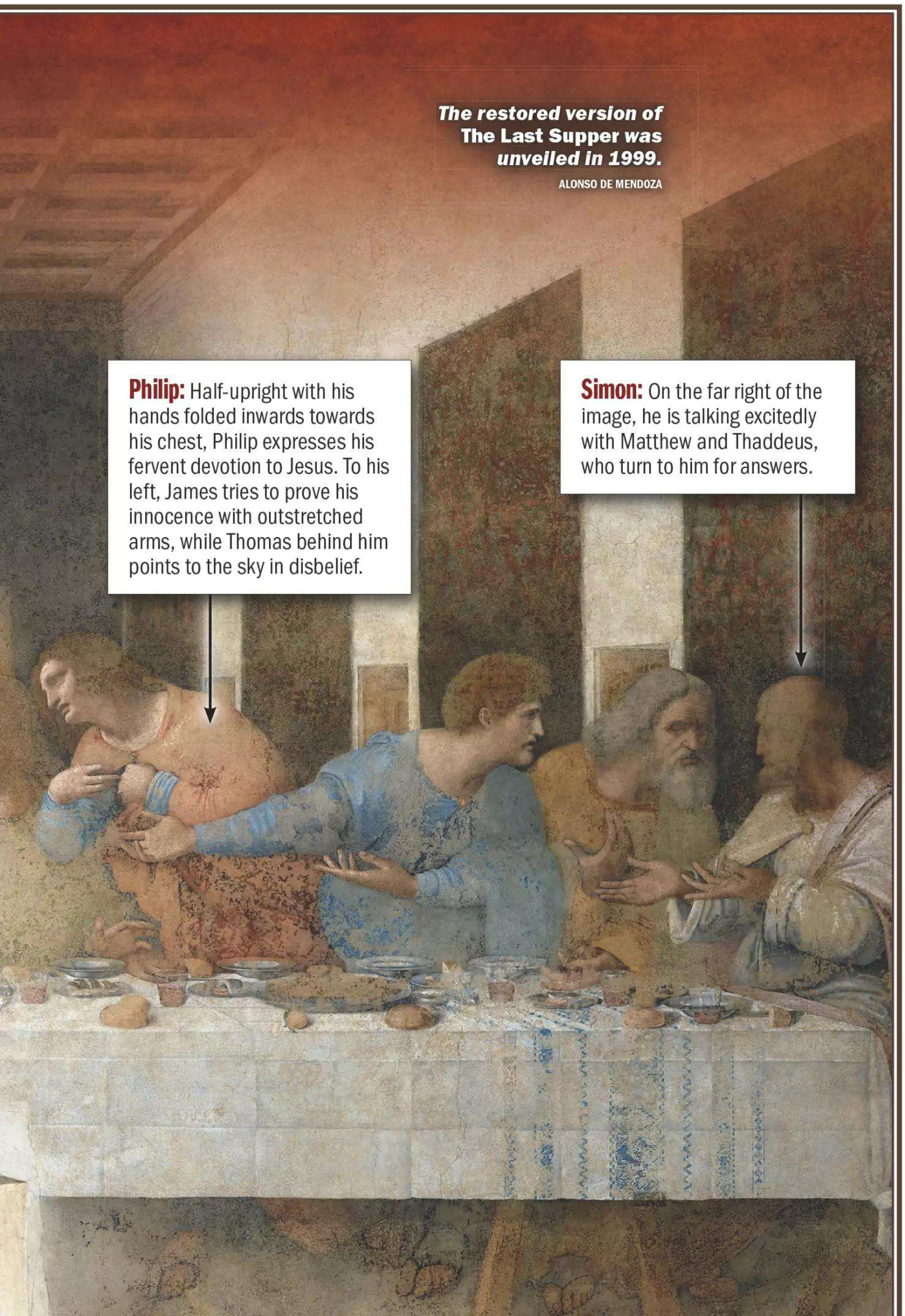
In 1489, Ludovico Sforza's messenger arrived at Master Leonardo's workshop with a commission for a colossal equestrian statue of the prince's late father. Unsurprisingly, the statue never materialised, but Leonardo did manage to produce a gigantic clay model that stirred the Duke's enthusiasm.

But then Ludovico Sforza lost interest – because a French invasion was imminent. He confiscated the bronze that was to have been used for Leonardo's equestrian statue and turned it into cannons. When the French finally invaded in 1499, Sforza gave up without a fight and fled the city.

Leonardo met the Pope's son

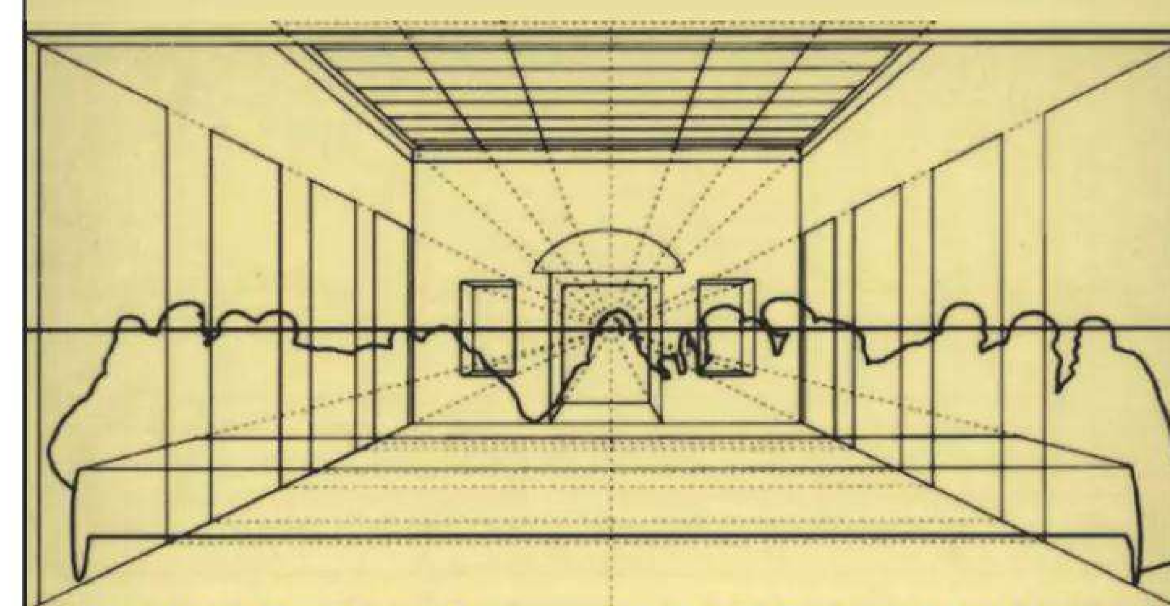
With Sforza's escape, Leonardo had lost his patron and now the French were in town – Leonardo decided it was time to return to Florence.

Before his departure, however, he had time to meet the French King Louis XII, ▶



The restored version of The Last Supper was unveiled in 1999.

ALONSO DE MENDOZA



The Last Supper *measures 8.8 x 4.6 m and is situated in the Convent of Santa Maria delle Grazie, Milan.*

Theatre tricks taught the master to cheat with perspective

In 1495, when Leonardo da Vinci started working on the enormous painting of the Last Supper, he had to use a method from the world of theatre that he himself called "complex perspective".

The lines from the walls and ceiling move more steeply towards the vanishing point than they normally would in a painting. The distortion of perspective was to ensure that the painting looked right no matter where the viewer was in the room – just like when the audience in the theatre sat in different seats.

The table is too narrow because the width of the image distorts the depth of perspective, so there is not enough room for the many disciples all sitting on the same side of the table. Notice how close Judas's right elbow is to the front edge of the table.

In permanent decay

1518: Just 20 years after the painting's completion, the paint started to peel away because Leonardo insisted on using oil paint on the plaster wall instead of painting a fresco.

1652: The painting was so faint and deteriorated that the monks of the monastery took the liberty of making a hole in the wall and fitting a door. In doing so, they cut off Jesus's feet.

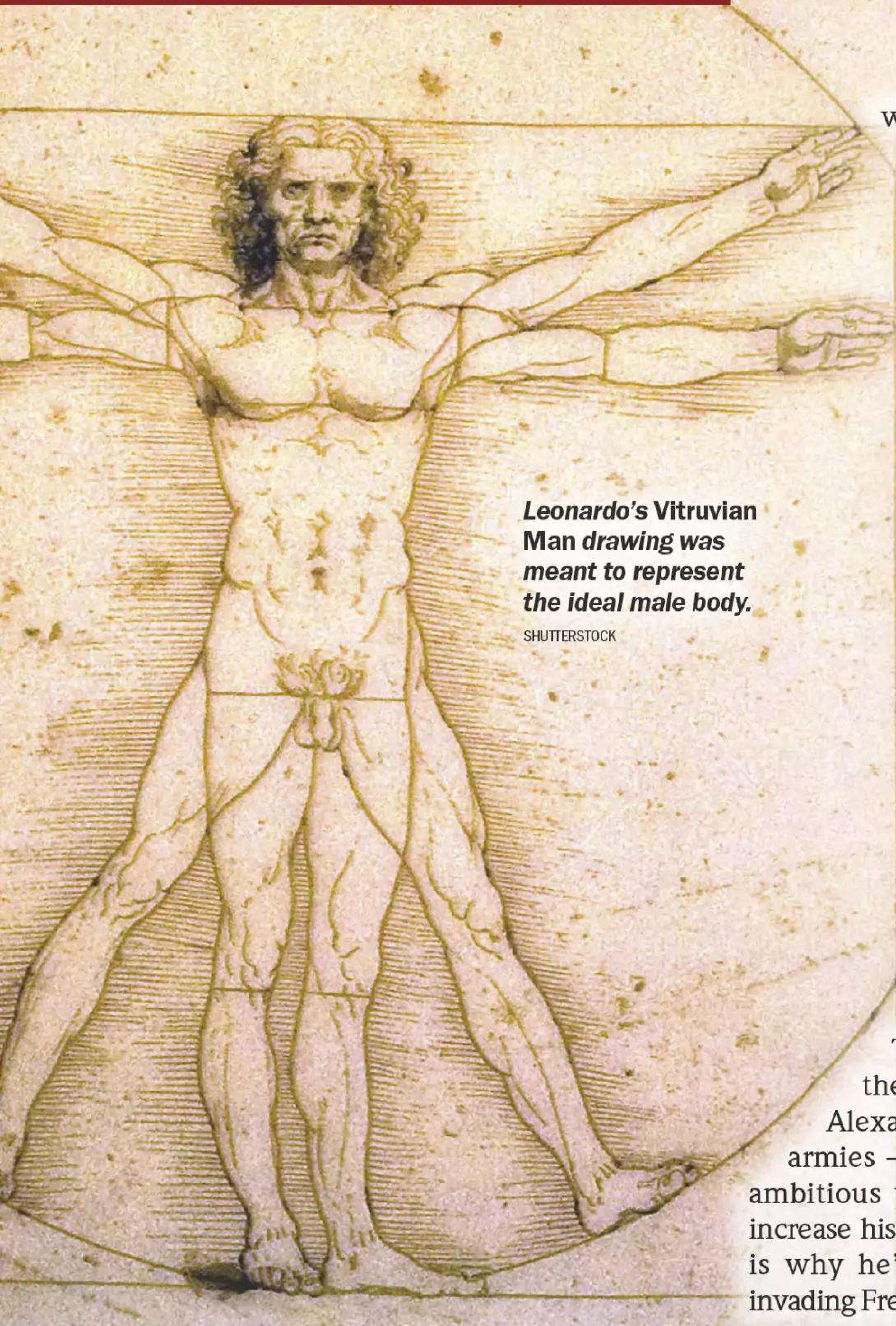
1726: A conservator quickly decided to fill in the peeling areas of the painting with oil paint and a layer of varnish on top.

1760s: A new conservator removed the old conservator's work. He then painted over the half-peeled faces with his own – showing little regard for the original work. However, a public outcry forced him to stop at just three faces.

The French Revolution: Anti-church vandals scratched out the apostles' eyes and the convent of Santa Maria delle Grazie was used as a prison.

1900s: Two cleanings slowed down the decay without causing more damage.

World War II: The monastery was hit by Allied bombs, but Leonardo's work was saved by sandbags piled up in front of it.



Leonardo's **Vitruvian Man** *drawing was meant to represent the ideal male body.*

SHUTTERSTOCK

who immediately after his arrival in Milan had gone to the Convent of Santa Maria delle Grazie, where Leonardo had laid the final brushstrokes on the huge commissioned work *The Last Supper* just one year before.

So captivated was the king by the painting that he enquired about the possibility of bringing the wall with the painting back to France, which his advisors counselled against.

Along with the French king, the commander Cesare Borgia arrived in the city. The 24-year-old Cesare was the son of the current Pope, Alexander VI, and led the papal armies – but most of all he was an ambitious young man who hoped to increase his power and influence, which is why he'd allied himself with the invading French. In Milan, the Pope's son was so interested in Leonardo's drawings of various war machines and weapons that the Italian painter showed him all his sketches before he left the city.

Leonardo turned homewards

In March 1500, Leonardo reached his home in Florence. With him was a large entourage of lovers, assistants and pupils. The master was approaching 50 years old, but he felt well after his return and worked productively. He even accepted a commission for a portrait of a rich silk merchant's beautiful wife named Lisa Gherardini. The world would later come to know her as the *Mona Lisa*.

However, in the spring of 1501, the warlord Cesare Borgia set his sights on Florence, and Florentines cowered in fear. In May, Cesare's invading army stood at the city walls, but after long negotiations, the city managed to escape capture by paying 36,000 florins. Cesare returned the following year, and this time the city paid with its finest artist and engineer: Leonardo.

Engineer for ruthless warlord

Leonardo set off to take up his new job as a technical and military expert for Cesare Borgia. In the summer of 1502, he arrived at his new patron's headquarters in the city of Urbino in the Romagna region. Here, Leonardo was issued a passport with the

Leonardo cut corpses

Throughout his life, Leonardo da Vinci showed great interest in understanding how the human body worked.

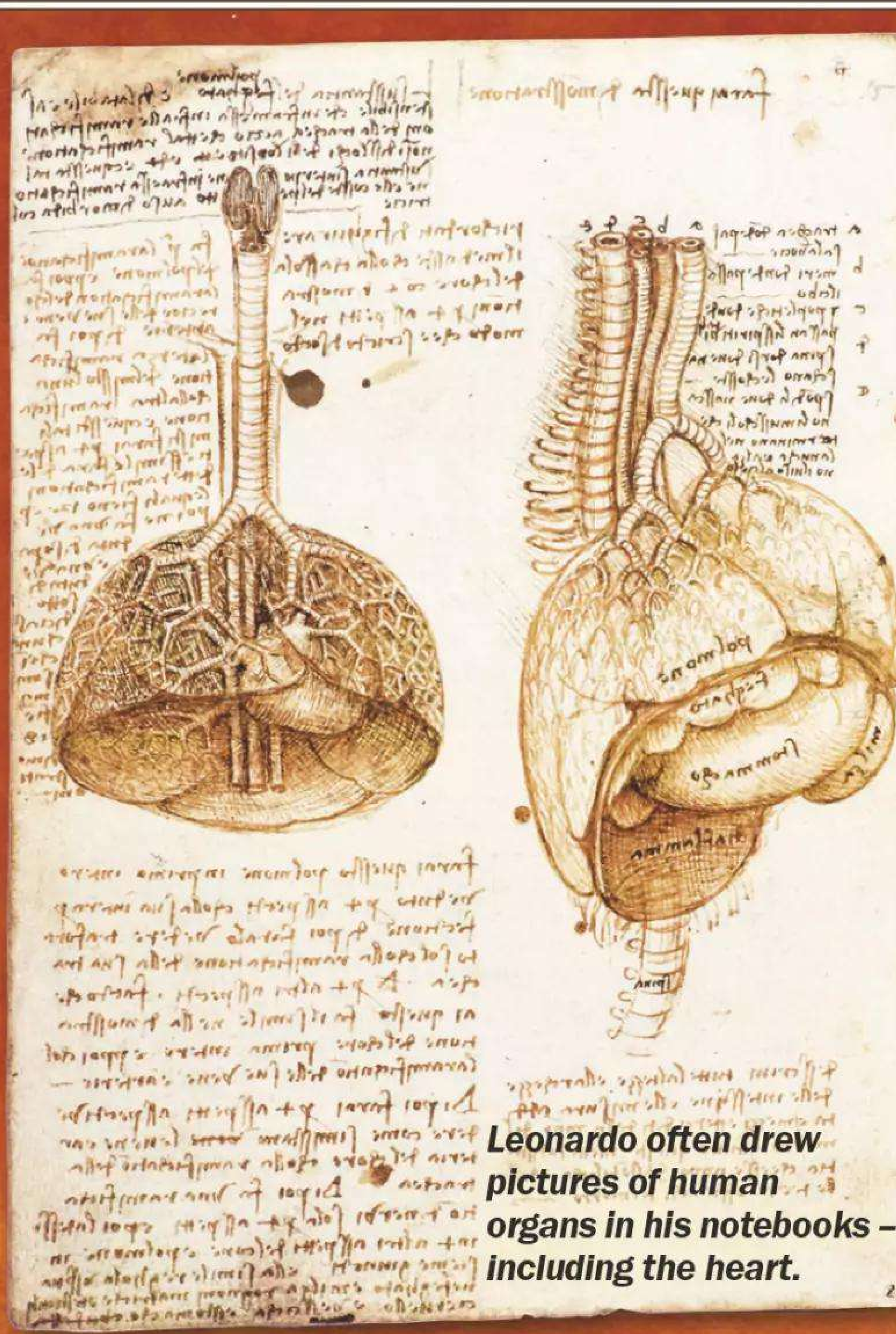
Human anatomy was of great interest to Renaissance artists. By understanding the muscles and movements of the body, they were able to create more lifelike representations of humans – and few knew more about the subject than Leonardo da Vinci.

Throughout his life, the inquisitive Italian dissected countless corpses. His goal was to map the body's muscles, tendons and organs – and to reproduce them as realistically as possible in drawings.

The mystery of the heart was Leonardo's greatest endeavour. The Italian's great love of hydraulics led him late in life to discover the force that caused the heart to pump blood around the body. Leonardo realised that blood circulated through intricate branches of veins and that "all the veins and arteries arise from the heart", as written in his notes.

During his dissections, he had discovered that the heart valve could open and close. Leonardo hypothesised that the movement created a pressure that caused blood to move through the main artery. The movement of the valve was a result of that same blood flow.

It wasn't until 450 years after the old master's death that his theory of the heart valve and blood flow was accepted by medical science.



Leonardo often drew pictures of human organs in his notebooks – including the heart.

IMAGESELECT

title of chief engineer, after which he set off on a tour to inspect fortifications and ports in Cesare's territories.

However, Leonardo was soon distracted from his expert military duties and started working on a thesis on the density of water. His greatest military work during this period was detailed city maps with a bird's eye view, which made it easier to plan military attacks.

Leonardo generally disliked his new patron. Wherever Cesare's army advanced, the soldiers murdered, raped and mutilated the local population. No longer in league with the French, the Pope's brutal son was working to conquer land for himself.

After just eight months in his service, a sad and disillusioned Leonardo was allowed to return home to Florence.

Royal invitation saved da Vinci

However, his return home did not immediately bring much joy to the ageing master. In 1503, the city council assigned him the difficult and time-consuming task of decorating the town's assembly hall. The situation was made worse by the fact that Leonardo's young competitor Michelangelo – whom he certainly didn't like – was also commissioned to work on the project.

The following year, Leonardo's father, who'd had nine other sons in the meantime, died. They refused to share the inheritance with their illegitimate older brother, which frustrated Leonardo, who at that point in his career was struggling with money problems.

Luckily for him, the ageing star received an invitation from a big fan – Louis XII of France. The king asked him to return to Milan. But at first, the city council refused to let Leonardo leave because the councillors suspected he was once again running away from an unfinished piece of work. However, the French king's ambassador insisted, and in the end, the city council didn't dare oppose Louis's wishes. In 1508, Leonardo left the city and his unfinished work on the assembly hall.

Book publishing never materialised

Back in Milan, Leonardo resumed one of his great passions: mapping the anatomy of the human body. Dissection was not favoured by the Catholic Church, but it did not prohibit it. The master retaliated against the fundamentalists in his notes on dissection: "You should not be distressed that your discoveries come through another's death; rather you should rejoice that our Creator has provided an instrument of such excellence."

After hundreds of dissections, he solved the final mystery behind the heart valve's hydraulic mechanism. To benefit humanity, his notes on the discovery merely needed organising, editing and publishing. That never happened.

Instead, 60-year-old Leonardo travelled to Rome in 1513 because a war broke out between the French and Ludovico Sforza's son, who had regained power in Milan, over control of the city. Leonardo departed, and had 250 kg of goods transported to Rome. Most of his luggage was books and instruments, but also a handful of paintings that he was still trying to complete. In Rome, however, Leonardo struggled to find a new patron and quickly grew tired of the city.

Joy and death awaited in France

During a summit in December 1515 in Bologna, where Leonardo attended as an advisor to the papal delegation, he met the new king of France – 21-year-old Francis I.

"You should not be distressed that your discoveries come through another's death."

Leonardo on dissection.

A friendship between the 63-year-old Leonardo and the young king was born on the spot. Tall, broad-shouldered, strong and charismatic, Francis was also inquisitive and interested in a multitude of subjects like Leonardo. Francis greatly admired the old master and begged him to come with him to France. Leonardo relented and the king installed him and his entourage in a small mansion in the Loire Valley next to his own castle.

Francis required no output whatsoever from Leonardo and never pestered him about paintings. His only demand was that Leonardo stay at his court. Francis paid for his stay himself and provided every conceivable comfort.

But the master's health was failing. A stroke rendered his right hand useless, and shortly after his 67th birthday in April 1519, Leonardo wrote his will. With a heartbroken Francis at his deathbed, Leonardo breathed his last on 2nd May.

The possessions left behind included a sea of notebooks, theses in progress, unrealised inventions and unfinished paintings – because to finish something was to let it stagnate and die, and throughout his life Leonardo swore by dynamism and movement as the basic principle of life itself.

Price: $450 million.

The painting Salvator Mundi depicts Jesus with a crystal ball in one hand.

STEMOC & SHUTTERSTOCK

Prince bought expensive painting

Only 23 paintings are very likely to have been painted in whole or in part by Leonardo da Vinci. Most of them are in museums and have not changed hands in over a century. It therefore caused quite a stir when, in November 2017, auction house Christie's sold a supposed work by Leonardo titled *Salvator Mundi* for $450 million (around £360 million).

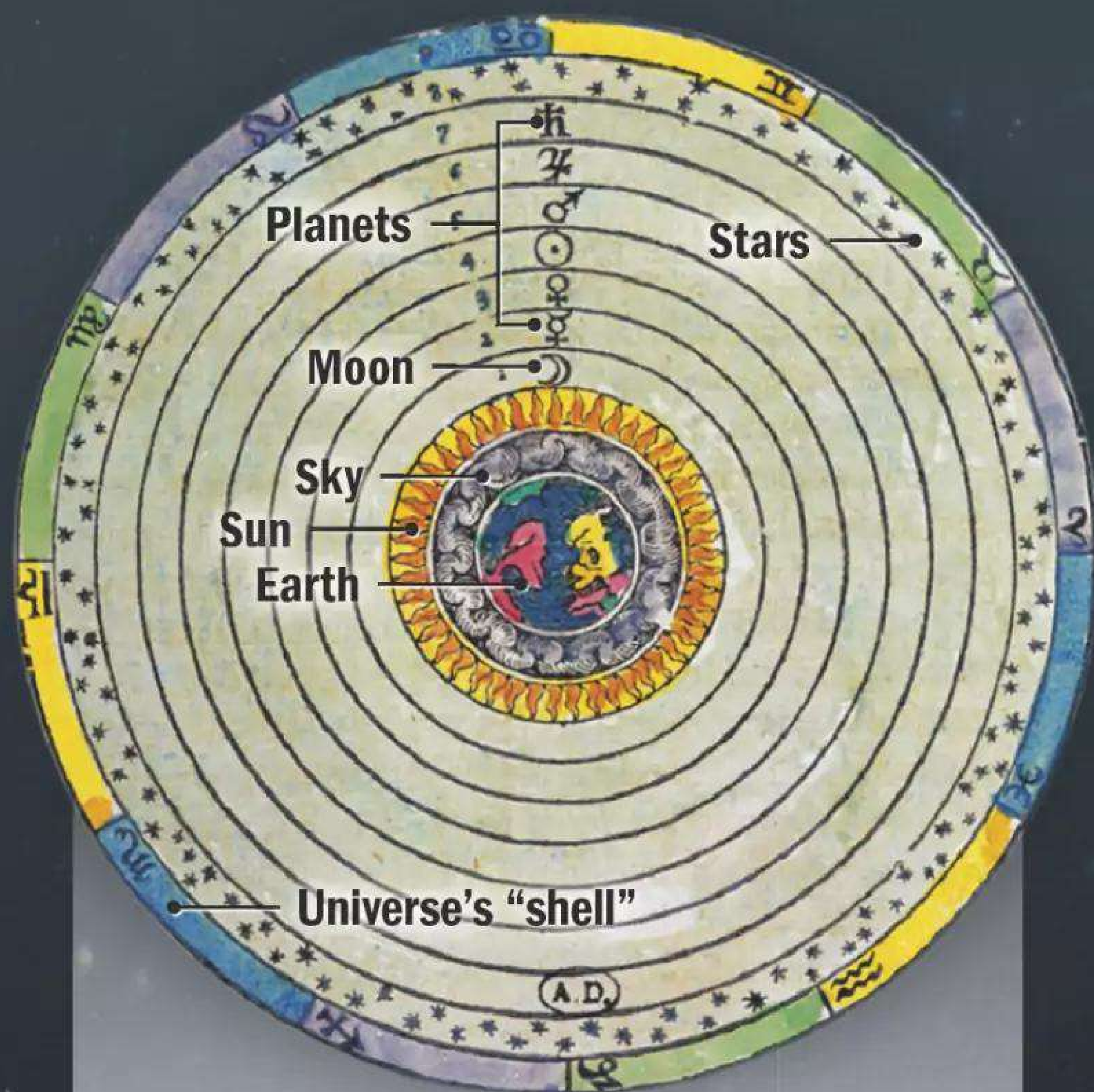
The price was the highest ever paid for a work of art and the buyer was a Saudi prince. Reportedly, the painting will eventually be exhibited at the Louvre Museum's branch in the United Arab Emirates. Every time a new painting turns up where there's a strong presumption that it is by Leonardo, the experts sit up and take notice:

Leading art experts are flown in to compare the painting with other known Leonardo works and assess whether it was painted by the master himself.

A carbon-14 sample is taken to determine its age.

Photographs from multispectral cameras are used to examine painting technique and brush strokes.

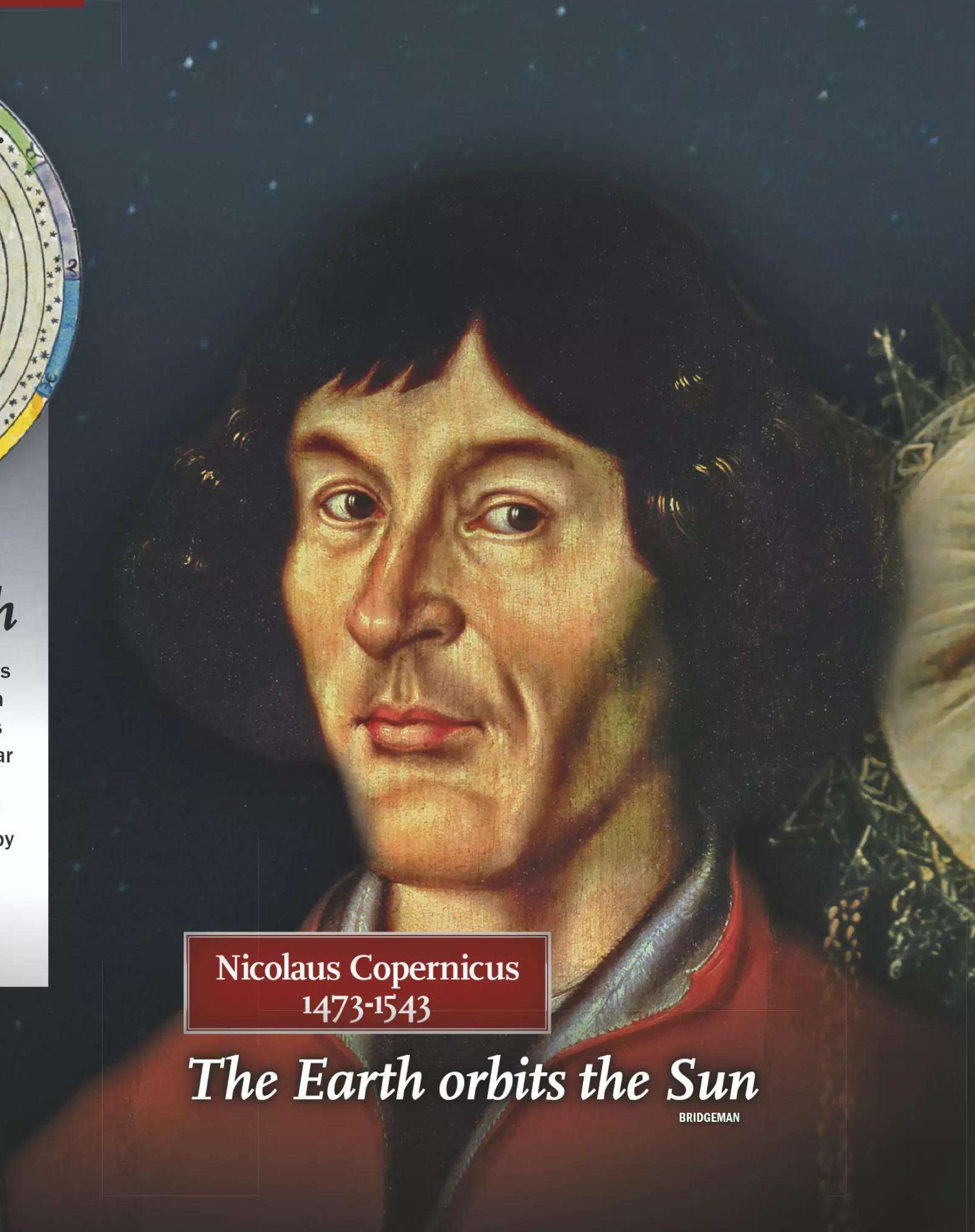
The fingerprints need to be analysed. Leonardo often used his fingers to erase strokes. Experts compare fingerprints with prints on works known to be his.



Ancient Greece inspired Church

For over 1,400 years, the universe was neatly and symmetrically organised in geocentric fashion: the Earth lay at its centre, the planets' orbits were circular and the starry sky was fixed – all as part of a divine plan. The principles of this orderly universe were conceived by Aristotle but refined and presented in AD 150 by Claudius Ptolemy in his book *Almagest* and later adopted by Christian Europe.

BRIDGEMAN



Nicolaus Copernicus
1473-1543

The Earth orbits the Sun

BRIDGEMAN

Trio wreaked chaos on the divine order:

Astronom first three

Tycho Brahe
1546-1601

The universe isn't fixed

BRIDGEMAN

Johannes Kepler
1571-1630

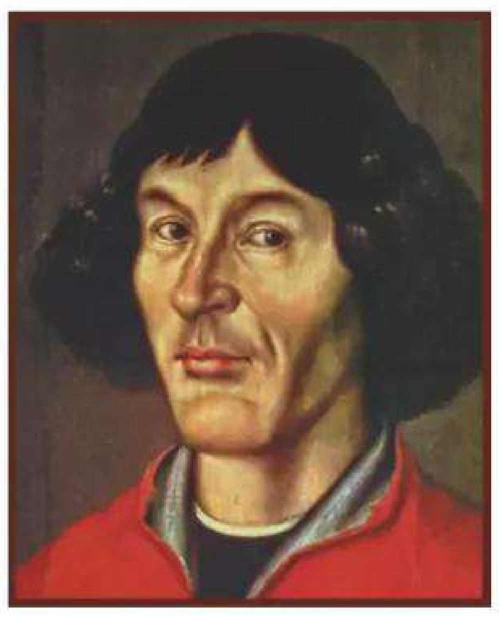
Planetary orbits are oval

BRIDGEMAN

y's stars

500 years ago, **Copernicus** *began by claiming that the Earth orbits the Sun. Soon after,* **Tycho Brahe** *and* **Johannes Kepler** *followed suit with equally outrageous claims that made the Church recoil. If they were right, God's creation was a mess.*

Nicolaus Copernicus: *The Earth orbits the Sun*



BRIDGEMAN

Attacked 70 years after his death

Five hundred years ago, astronomer Copernicus challenged almost 1,500 years of fixed beliefs about the Earth as the centre of the universe. In his new solar system, the Earth orbited the Sun – not the other way round – but 70 years after his death, Copernicus was labelled a heretic.

BY ELSE CHRISTENSEN

One day in 1496, Nicolaus Copernicus was listening intently, as he often did, to his teacher Domenico Maria Novara's lecture. Novara was one of the University of Bologna's most respected teachers of mathematics and astronomy, and therefore always worth listening to. But what Novara said that day made Copernicus's ears perk up.

Novara had measured the latitudinal positions of Italian cities and compared them with those given in the ancient work *Geografia.* According to his calculations, all the cities were more than one degree further north. Was this something that might indicate that the Earth's axis shifted over a long period of time? Copernicus was startled and a thought planted itself in his mind that would later send shivers down the spines of priests and commoners alike: maybe the Earth wasn't the static fixed point of the universe around which everything revolved – maybe the Earth was in motion?

Antiquity reborn

Copernicus was born in Torun, Poland, where he was raised by his uncle, one of Poland's most prominent churchmen with close connections to the Polish royal family. His uncle arranged for Copernicus to study at the best universities in Poland and in 1496, at the age of 23, he was sent to Italy.

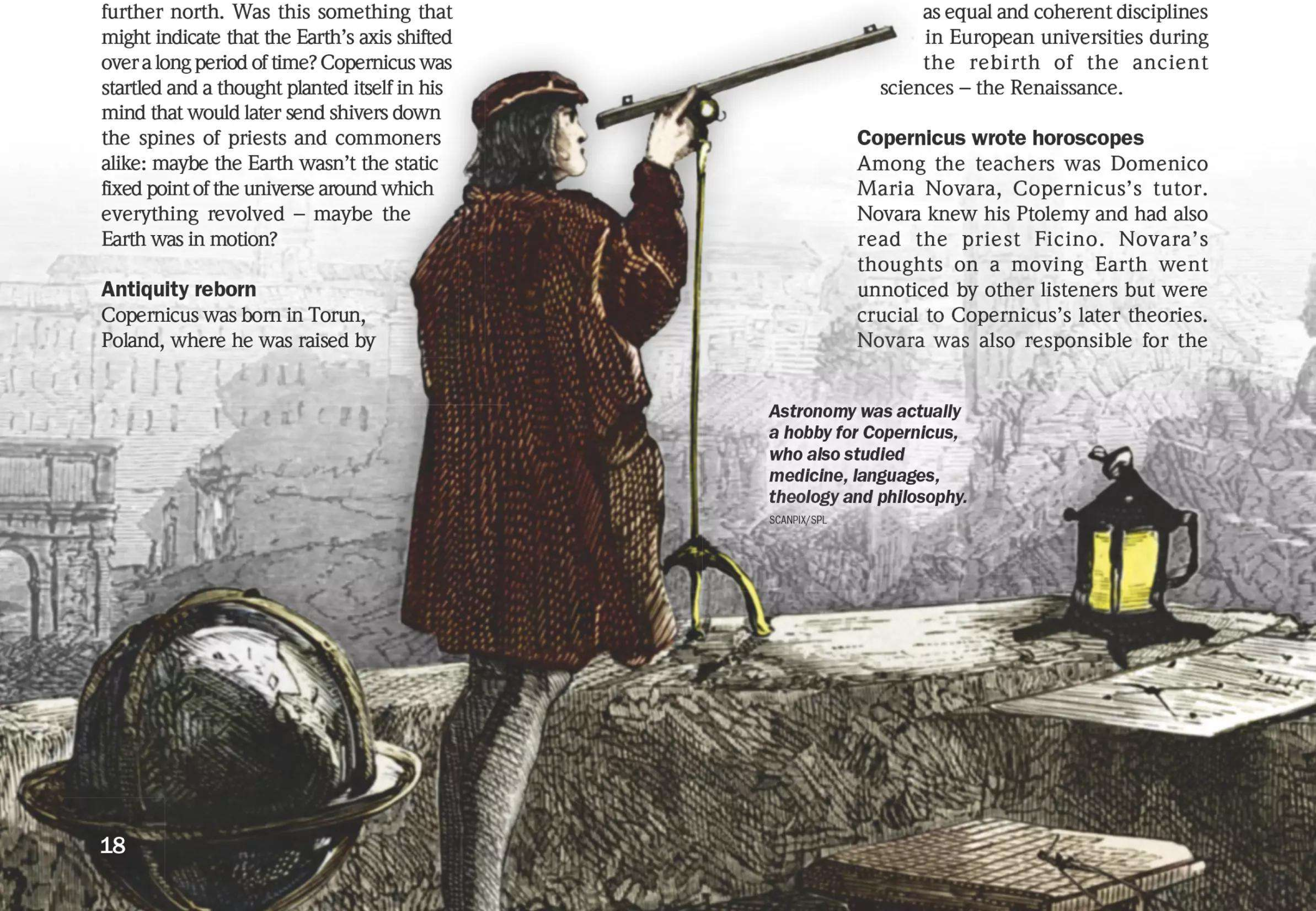
There, over 20 years earlier, the priest Marsilio Ficino had triggered a veritable scholarly landslide when he began researching, translating and publishing ancient Greek texts.

Europe's inquisitive minds were quick to pick up the thread. From tiny cells in isolated Central European monasteries to high-ceilinged libraries in the Byzantine Empire, scholars poured over the ancient scriptures like bookworms searching for answers to anything and everything.

The occult and the scientific flourished side by side in ancient thinking. In AD 150, for example, Ptolemy, the progenitor of the geocentric world view that placed the Earth at the centre of the universe, had also studied astrology extensively and had even written a book on the subject. As a result, maths, philosophy, astronomy and astrology were studied as equal and coherent disciplines in European universities during the rebirth of the ancient sciences – the Renaissance.

Copernicus wrote horoscopes

Among the teachers was Domenico Maria Novara, Copernicus's tutor. Novara knew his Ptolemy and had also read the priest Ficino. Novara's thoughts on a moving Earth went unnoticed by other listeners but were crucial to Copernicus's later theories. Novara was also responsible for the



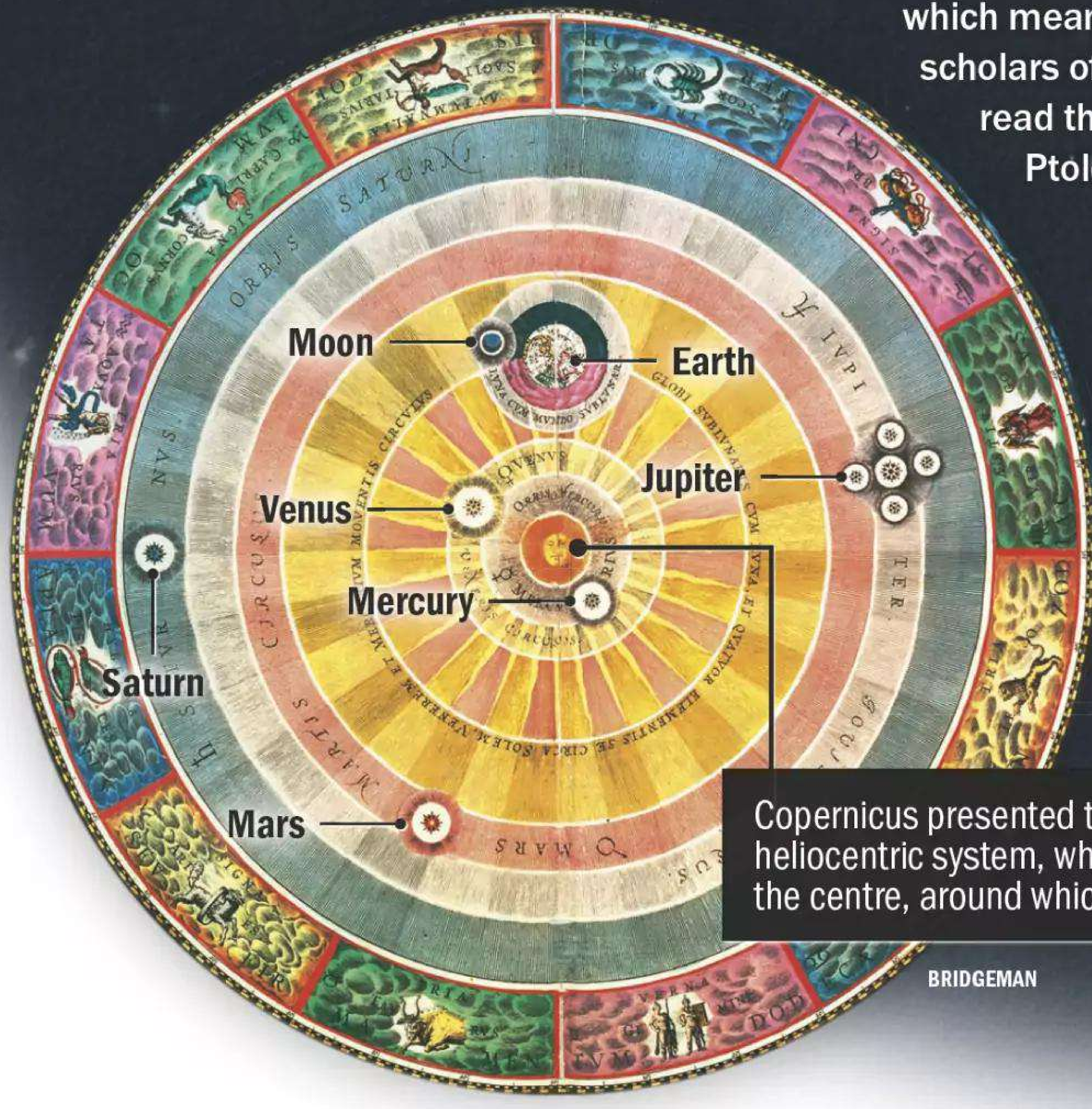
Astronomy was actually a hobby for Copernicus, who also studied medicine, languages, theology and philosophy.

SCANPIX/SPL

Other planets were overtaken by Earth

'The Earth is a sphere suspended in the centre of the sky, while the planets, Sun and Moon orbit around it.' This is roughly how the universe was presented in the ancient Greek model that had survived until Copernicus's time. At the University of Bologna, Copernicus learned Greek, which meant that, unlike most other scholars of the time, he could actually read the writings of Aristotle and Ptolemy in the original language. But he couldn't get the picture right. Some planets occasionally appeared to move backwards, a movement that was unthinkable in the model. Copernicus set out to solve the riddle, and after many observations and calculations, he had the answer: the planets did not move backwards but were overtaken by the Earth as they travelled around the Sun together, albeit in different orbits. "The diurnal movements of the stars and the annual motion of the Sun are only apparently and in reality the result of the daily rotation of the Earth on its own axis and an annual orbit around the Sun. It is the Sun that is at rest at the centre of the planetary system," he stated.

Although his discovery overturned centuries of belief, Copernicus essentially stuck to Aristotle's and Ptolemy's system. He continued to believe that the planets' orbits around the Sun were circular and, like the Greeks, had to resort to artifice to make the circles fit the observations.



Copernicus presented the so-called heliocentric system, where the **SUN** sits at the centre, around which the planets orbit.

BRIDGEMAN

annual publication of the university almanac. In addition to predictions about weather and celestial bodies, it also contained astrological predictions such as days and times when particularly dramatic events might occur.

Copernicus helped him with his work, and historians know that the man who would become a renowned astronomer compiled horoscopes in the process. Unfortunately, they were not edited and published, so history has no record of what kind of predictions Copernicus made. But the almanacs – with their mix of scientific observations, weather forecasts and astrological predictions – were popular in all reading circles.

Priest, doctor and politician

When Copernicus graduated with a doctorate in canon law at the age of 30, he devoted himself to his work as a priest in the city of Frombork in modern-day Poland. He was also involved in politics, economics and, not least, medicine, which he practised for the benefit and happiness of both the leading men of the Church and the town's poor.

It wasn't until his *De Revolutionibus Orbium Coelestium* (*On the Circular Motion of the Celestial Spheres*) that Copernicus set down the doctrine he had derived from Novara's teaching: a world view where the Sun – not the Earth – was the centre of the universe.

Church banned Copernicus's book

The book was published in 1543, the year Copernicus died, but its contents were known from the *Commentariolus* (*Little Commentary*) that the astronomer wrote between 1510 and 1514. Neither the commentary nor the book itself was criticised by the Catholic Church.

On the contrary, Copernicus was invited by Pope Leo X, along with other astronomers, to send him observations so that he could revise the calendar, which no longer corresponded to the seasons. The astronomer even dedicated his book to Pope Paul III.

The Church's reaction, or lack thereof, was not surprising. Although he challenged the so-called geocentric divine world view, Copernicus was deeply religious and did not see his findings as a rebellion against the Church at all. He saw the Sun as a symbol of God. "For, in this most beautiful temple, who would place this lamp in another or better position?" wrote Copernicus in his book. "Thus indeed, as though seated on a royal throne, the Sun governs the family of planets revolving around it." It was said that he had a first copy of his book thrust into his hands on his deathbed and then expired a happy man.

In 1616 – 73 years after Copernicus's death – the Inquisition put the book on the Catholic Church's list of banned books. The ban came in the wake of the Reformation, which split the Church and made the Catholic Church fear any form of heresy.

SCANPIX/SPL

Copernicus's work wasn't published during his lifetime. According to folklore, he was given a newly printed copy on his deathbed.

Tycho Brahe: *The universe isn't fixed*

BRIDGEMAN

Stargazed from his own island

Tycho Brahe's discovery of a dying star gave astronomers their first insight into the vastness of the universe – and challenged the Church and Greek philosophers' idea of an unchanging sky. The discovery brought fame to the eccentric Brahe, but it was his stargazing and alchemy skills that made him rich.

Tycho Brahe was on his way home for dinner, but the sight that greeted him in the dark sky on 11th November 1572 made him forget about his stomach. In the centre of Cassiopeia, the familiar constellation, a new star shone brightly.

The astronomer could hardly believe his eyes, but others confirmed the unusual sight. And for the next few months, he watched the star daily as it slowly faded to a dim yellow, then orange and red, before finally disappearing completely. Brahe became the first to describe a supernova, an exploding star. This discovery, together with his meticulous and precise measurements of the movements of the heavenly bodies, made him one of the absolute pioneers of astronomy.

At the time, however, he was known for something completely different: as astrologer to the Danish King Frederik II, he could twist the king around his little finger, and his skills as a stargazer earned him both personal wealth and the means to study and surround himself with the great scientists and patrons of the time.

Brahe predicted sultan's death

A career as an astrologer may have been written in the stars, but for Brahe's parents, it came as a surprise. He was destined to become a civil servant. However, astronomy appealed more than working for the royal family, and when Tycho was sent on an educational tour as a young nobleman, he studied planets and star maps at universities in German cities such as Wittenberg and Rostock.

At the same time, his bold predictions drew great scrutiny. He predicted the death of the Turkish Sultan Soliman in 1566 – and was ridiculed when the sultan turned out to have already died.

After the discovery of the stellar explosion, which he predicted would lead to "great and unusual effects … new conditions in the kingdoms, completely different from before", Frederick II employed him as court astronomer. The king was ambitious and vain on behalf of Denmark and himself, and with Tycho at his side, he could appear as a cultural patron and gain insight into both his and the kingdom's future prospects.

The king generously gave the island of Hven in Öresund to Tycho Brahe as a personal fiefdom for life.

At the same time, Frederick gave him several fiefs in Norway, the Kullen Lighthouse in the south of Sweden, the Chapel of the Three Kings in Roskilde and 500 riksdaler a year, as well as money to build observatories

Brahe was given the island of Hven by the Danish king. There he built two observatories as well as a paper mill, printing press and bookbindery, so that his discoveries could be quickly published.

MARY EVANS

in Uranienborg (1576) and Stjerneborg (1584). Brahe soon expanded with a paper mill, printing press and bookbindery, so that he and the scientists he gathered around him on Hven could publish their own works.

Received 1% of kingdom's wealth

Historians estimate that Brahe's holdings equalled 1-2 per cent of the Danish state's possessions, so the stargazer had no trouble funding his more curious interests.

On Hven, he often gathered friends for dinner, and during these feasts and drinking sessions, his court jester, a dwarf named Jeppe, was treated like a dog. At the table, Jeppe sat at Brahe's feet and received treats. Jeppe was, according to Brahe, psychic, and one of the highlights of the feast was the jester's predictions. In addition to Jeppe, the astronomer was accompanied by a tame moose, which also accompanied him on his travels.

But Brahe also worked hard. He designed the most advanced instruments of the time, making it possible to measure the movements of the celestial bodies with much greater accuracy. He also drew up horoscopes for the princes, and every year he delivered an almanac in which the king could follow the seasons of the year and see how the stars were positioned in relation to the future of the kingdom.

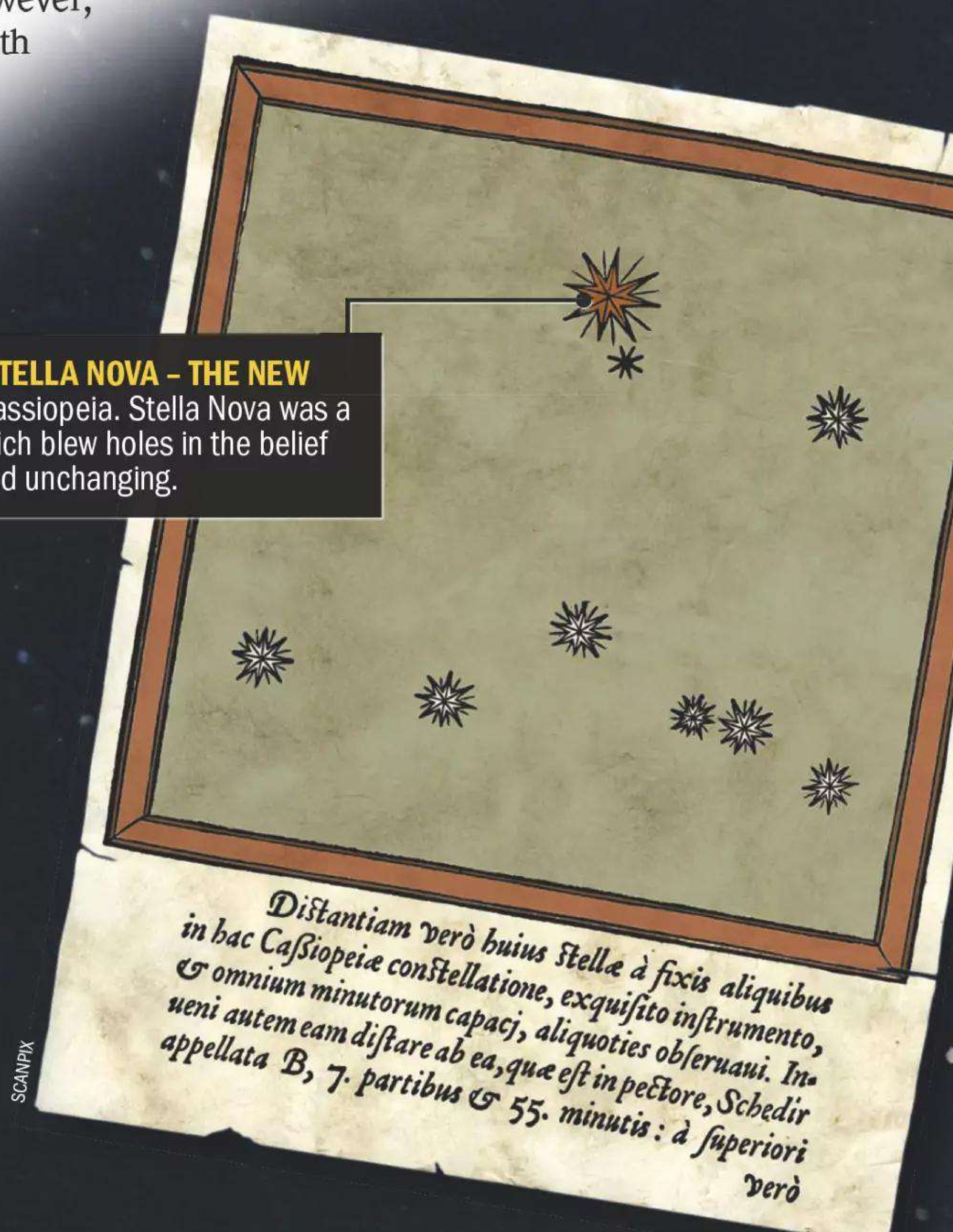
Brahe was also keenly interested in medical alchemy, working on the theory that nature contained a cure for all ailments. He had a large herb garden adjacent to his laboratory, where he grew medicinal plants and experimented eagerly with a cure for plague and a life-prolonging elixir, among other things.

New king shut the door

Brahe's good life came to an abrupt end in 1588. Frederick II died and his son Christian IV came to the throne. Although Brahe drew a horoscope that promised the ruler both happiness and wealth, he never won the new king's favour. Christian IV didn't share his predecessor's penchant for astrology. On the other hand, he – and the councillors who ruled the country until the king came of age – were fussy about the kingdom's holdings, and it bothered him that Brahe let the lighthouse on Kullen and the chapel in Roskilde decay while he stargazed. Christian slammed the door shut, and an embittered Tycho Brahe began looking for another benefactor. In 1597, the year after Christian was crowned king, he left Denmark. He travelled to Prague, where he became a highly valued court astronomer for the alchemy-loving Holy Roman Emperor Rudolf II.

The joy was short-lived, however, because after a dinner party with a good friend on 13th October 1601, Brahe fell ill. He developed a fever, became faint and slipped in and out of consciousness before he died 11 days later, on 24th October 1601.

Brahe's sudden death has led to much speculation – from a burst bladder to premeditated murder. The story of a burst bladder is flatly rejected by doctors, but analyses of the astronomer's hair reveal high concentrations of mercury. Mercury was an integral part of alchemy, so Brahe may well have inadvertently poisoned himself over time.



Tycho Brahe's records show **STELLA NOVA – THE NEW STAR –** in the constellation Cassiopeia. Stella Nova was a supernova – a dying star – which blew holes in the belief that the universe was fixed and unchanging.

Brahe followed planets to the end

Tycho Brahe was as skilful an instrument maker as he was an astronomer. He either bought and improved instruments or designed them himself.

Unlike previous astronomers, Brahe didn't simply observe the celestial bodies at specific times; the royal astronomer followed them zealously along their entire orbit, discovering anomalies that others had missed.

The accurate observations enabled Brahe to reject the ancient belief that everything outside the "atmosphere" – on the other side of the Moon – was fixed and unchangeable. Or in the words of the Church, that the stars were fixed in the firmament as on the day God created them. Brahe uncovered definitive proof when he observed his Stella Nova, a new star, in the distant constellation Cassiopeia on 11th November 1572. Brahe observed what turned out to be a supernova, an exploding star, and followed it as it slowly disappeared.

However, the great astronomer was not always right. To his dying day, he claimed that the Earth was the immovable centre of the universe.

Johannes Kepler: *Planetary orbits are oval*

BRIDGEMAN

Child prodigy figured it out

A childhood illness damaged Johannes Kepler's eyesight and prevented him from observing the starry sky, but unusual numerical and mathematical abilities secured him a great career. The frail boy ended up as an astrologer for the Holy Roman Emperor – sending the planets on their proper elliptical course.

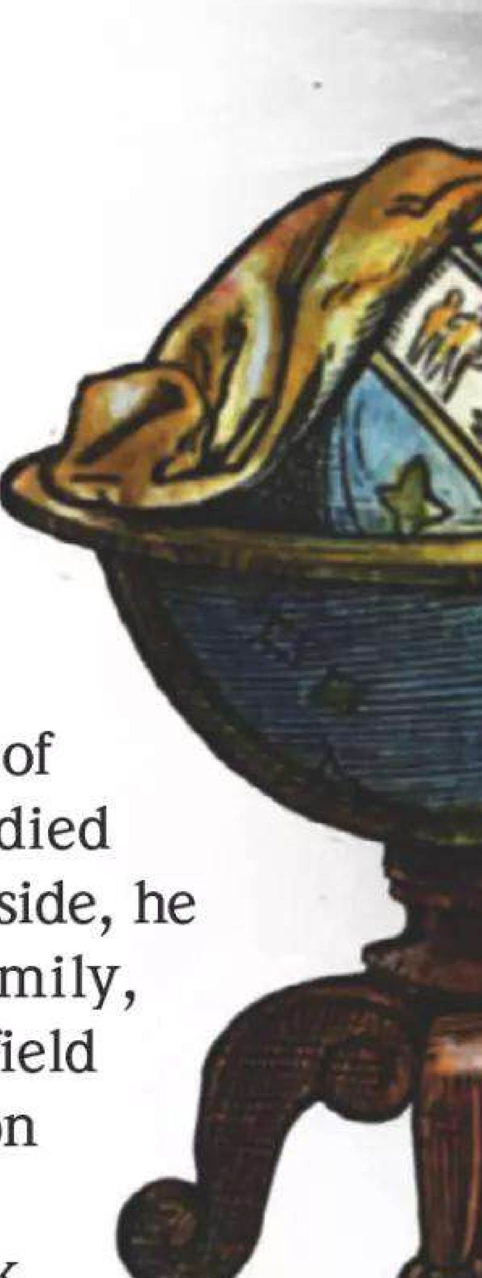
In the year 1577, a large comet glided across the sky. The phenomenon could be seen from all over Europe and attracted the attention of scientists and the general public alike. People flocked out into the open air to see the celestial body, whose tail, according to contemporary accounts, "travelled across the sky like the brightest lightning".

Among those who went out to see the comet were six-year-old Johannes Kepler and his mother, who watched from the top of a hill. Mother and son must have enjoyed the free recreation, because such pleasures were rare occurrences in Kepler's childhood home.

The Kepler family, who lived in the town of Weil in southern Germany, may have belonged to a noble family, but they had no money. The father, who had to earn his living as a mercenary, had left home the year before and then disappeared without a trace. For Kepler, the sight of the comet was far more than a momentary distraction; it was the beginning of the interest in the heavens that would earn him great renown as an astronomer, imperial advisor and personal astrologer to one of history's greatest generals.

Emperor protected Kepler

The journey to the stars did not begin promisingly for little Johannes. Afflicted with smallpox as a child, the disease damaged his eyesight and crippled his hands, so that he would never be able to observe the heavens for himself. However, he had an extraordinary talent for numbers and maths, and often impressed guests at his grandfather's inn by calculating complicated number puzzles. Johannes's talents caught the attention of the Duke of Württemberg, who secured the poor nobleman a scholarship at the University of Tübingen, where Kepler studied astronomy and maths. On the side, he compiled horoscopes for family, friends and acquaintances, a field in which he gained a reputation for excellence.



After his studies, Kepler took a position as a maths teacher at a school in the city of Graz, Austria, where he experimented with astronomy on his own.

At the age of 25, he published a large and elaborate work on classical Euclidean geometry, an important component of astronomy that prior to the invention of telescopes relied largely

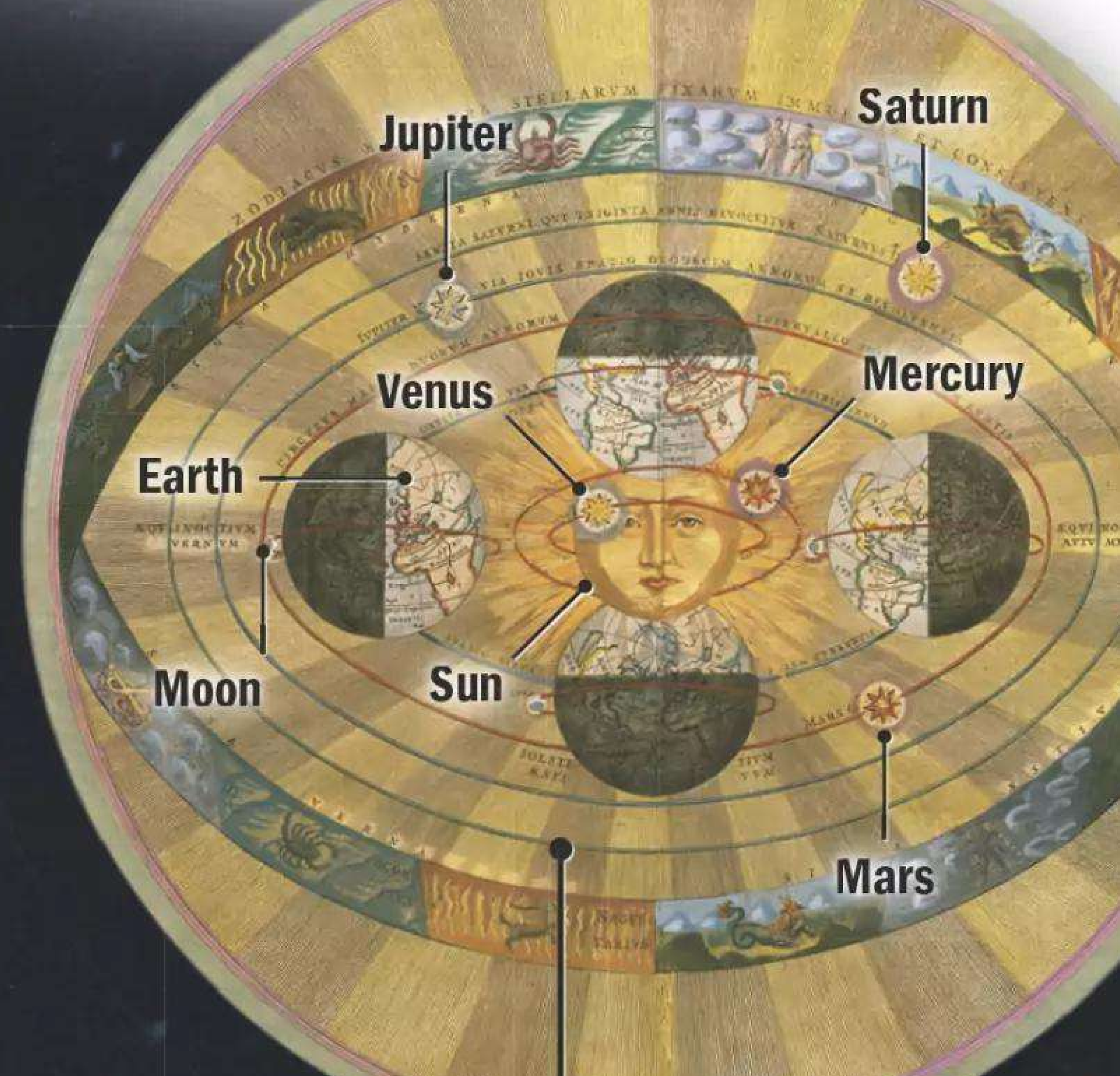
Divine circles were replaced by ellipses

The ancient Greeks wanted the Sun and planets to orbit the Earth in perfect circles. The round shape symbolised the harmony of everything. And Christian Europe adopted the image as an example of God's perfect creation. Even Copernicus, who moved the centre of the universe from the Earth to the Sun, kept the circles.

Kepler's childhood illness meant that his eyesight was impaired and he was unable to make close observations himself. Instead, he used other people's records of planetary movements and celestial changes as the basis for his calculations. In particular, Kepler used Tycho Brahe's very precise records of the extremes of Mars's orbit. But no matter how many times Kepler did the maths, he couldn't get the observations to fit a circular orbit. It was only when he tried elliptical orbits that the complex maths added up.

Kepler put forward his ideas in the publication *Astronomia Nova* in 1609. The discovery, known as Kepler's First Law, confirmed Copernicus's claim that the Sun was the centre of the solar system.

This paved the way for the next generation of astronomers to reveal that our solar system is just one of many in the infinite universe.



Kepler calculated that the planets orbit the Sun in **ELLIPTICAL ORBITS.**

BRIDGEMAN

The kings and emperors of Europe paid princely sums for horoscopes. It made astrology a lucrative profession for Kepler and his contemporaries.

GRANGER/POLFOTO

on calculation. Kepler's writings impressed Danish astronomer Tycho Brahe. He was court astronomer in Prague at the time and invited the young maths teacher there as a partner.

Brahe commissioned Kepler to continue his calculations of the orbit of Mars. The role led to Kepler's discovery that the orbits of the planets were not circular as assumed, but elliptical – another attack on the traditional, orderly world view favoured by the Church and traditional science.

On the run from Catholic agents

Kepler worked as Brahe's assistant when he took over as court astronomer to Emperor Rudolf II of the Holy Roman Empire. The position involved compiling horoscopes to help the emperor rule the empire. But the work was risky. By 1520, Luther had torn Europe apart with his Protestant rebellion against the papal state and greedy bishops. And throughout Europe, Catholics were now launching the Counter-Reformation against the Protestants. This was also true in the Holy Roman Empire, where the Lutheran Kepler could only feel safe under the personal protection of the Emperor.

This situation changed when the ageing emperor was forced to abdicate by his own brother in 1611. As the dethroned Rudolf's trusted advisor, Kepler had no place at his brother Matthias's court and had to move to Linz, where he returned to teaching mathematics. But Kepler was not safe there either. Catholic agents pursued him, determined to stop the spread of his heretical world view. His books were burned and in 1625 his entire library was seized.

Horoscope led general to war

Not all Catholics were sceptical of Kepler, however. In 1608, he had been contacted anonymously through an intermediary by Albrecht von Wallenstein, a skilful young army officer with high political ambitions. Wallenstein wanted a horoscope, which Kepler dutifully delivered – probably knowing who the anonymous buyer was.

In 1624, while the Thirty Years' War raged between the princely houses of Europe, Kepler heard again from Wallenstein, who had now become the most important general in the Empire. Wallenstein had a strong interest in astrology, and he commissioned Kepler to provide him with calculations so that his astrologers could create horoscopes for him.

Kepler also drew up some of the horoscopes himself, which Wallenstein blindly trusted. His belief that the stars had destined him for greatness may have been a contributing factor to the general's lust for power, according to historians.

When Wallenstein began plotting to depose the Emperor himself, things went too far. On 24th February 1634, he was killed by his own soldiers, with the Emperor's approval. Kepler had finalised Wallenstein's horoscope by March 1634, a month in which he predicted "terrible unrest". Kepler did not live to see his prophecy almost come true. His flight continued to Regensburg, where he died on 15th November 1630 after a short illness.

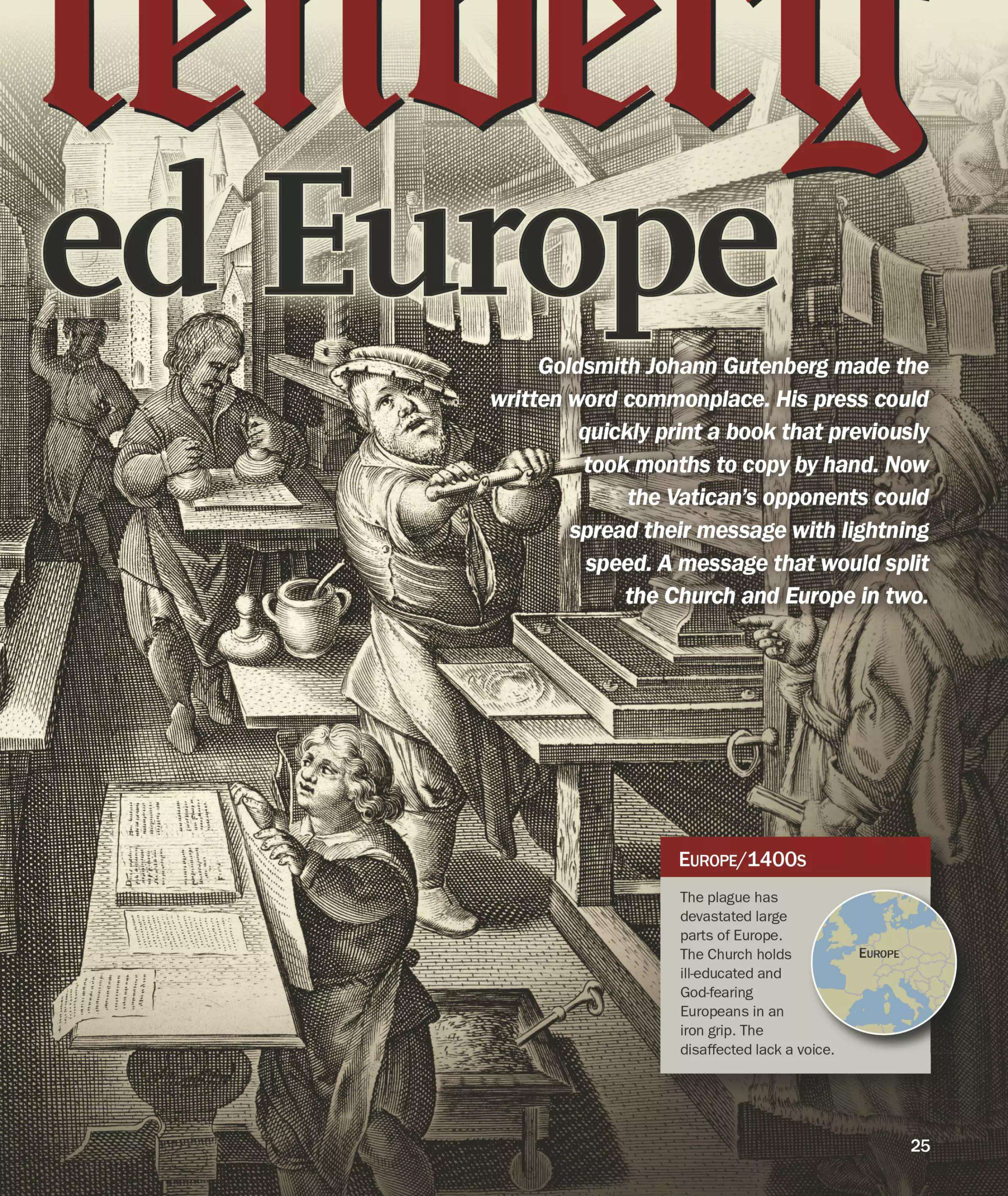
Printing press became the main weapon against the Pope:

Gu
divid

Gutenberg's printing press offered an early taste of industrialisation. Every man had his job – like on an assembly line.

POLFOTO/ULLSTEIN BILD & BRIDGEMAN

tenberg
ed Europe



Goldsmith Johann Gutenberg made the written word commonplace. His press could quickly print a book that previously took months to copy by hand. Now the Vatican's opponents could spread their message with lightning speed. A message that would split the Church and Europe in two.

EUROPE/1400S

The plague has devastated large parts of Europe. The Church holds ill-educated and God-fearing Europeans in an iron grip. The disaffected lack a voice.

BY STINE OVERBYE

In Victor Hugo's 1831 novel *The Hunchback of Notre-Dame*, a learned man stared in awe at the work in his hands. For the first time, he leafed through a printed book, admiring the perfect lettering in straight lines. He looked up to contemplate the gigantic cathedral before him:

"This will kill that," he said. Hugo's fictional character had predicted that the printed word would destroy the Church leaders' monopoly on the truth.

The Vatican's version of Christianity had always stood unchallenged. Only the Church had the money to allow scribes to spend half a year producing a single book. With Gutenberg's invention, the written word was no longer the preserve of popes, cardinals and bishops.

Now, fresh new opinions could sweep across Europe – including those of one Martin Luther, who would exploit the new technology in such a way his ideas would change the world.

Capitalist revolutionised the world

Johann Gutenberg was an entrepreneur with a keen eye for any opportunity that might make money. In the German (now French) city of Strasbourg in 1439, around 250 kilometres south of Aachen, the goldsmith saw his first chance to make a fortune. Every seven years, hundreds of thousands of pilgrims flocked to Aachen to catch a glimpse of some sacred pieces of cloth. For two weeks, the fabric that the newborn baby Jesus had been wrapped in on Christmas night was put on display alongside the robe worn by the Virgin Mary during childbirth.

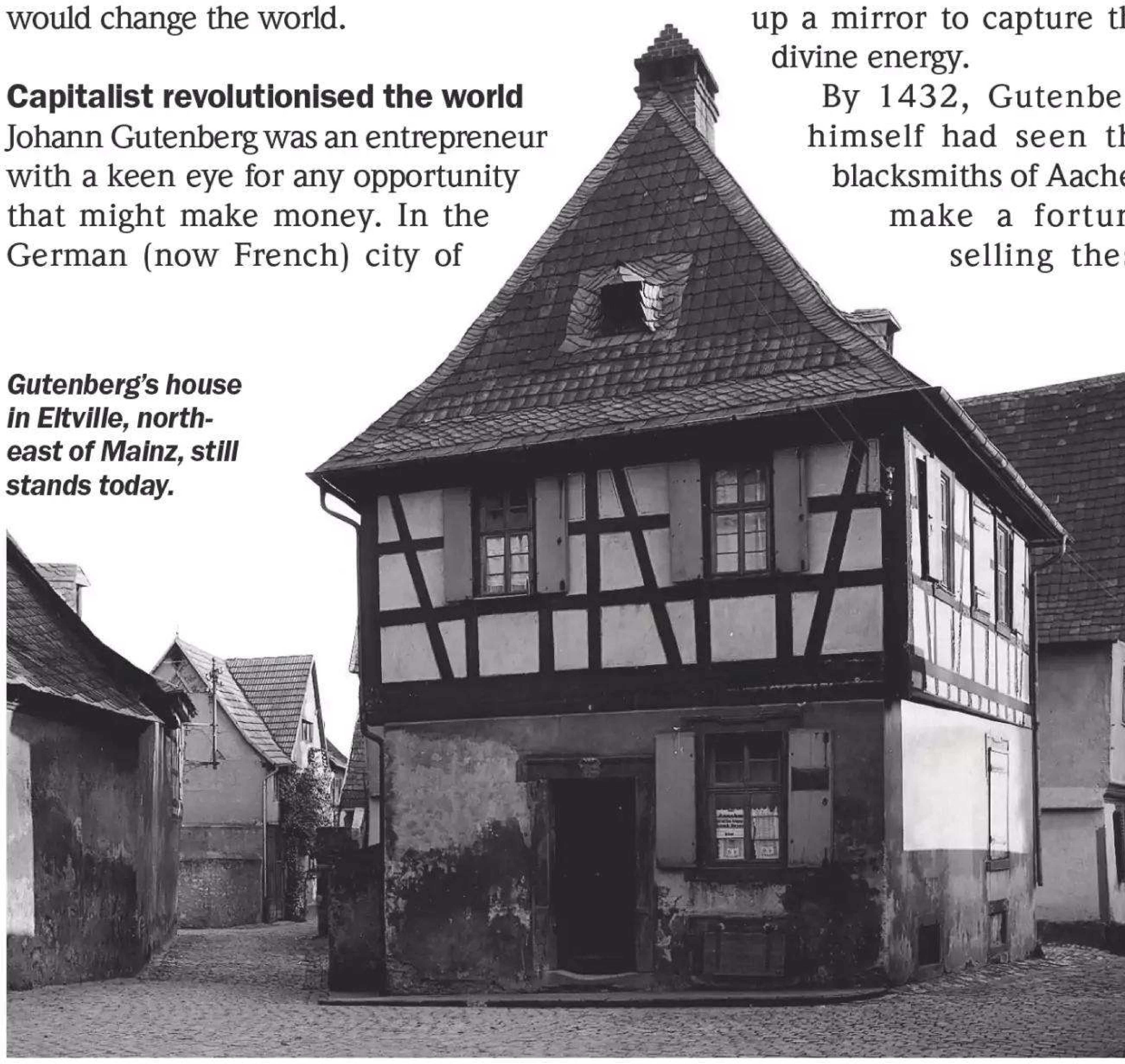
Like invisible rays from the sun, spiritual streams radiated from the garments, and anyone touched by those streams would be guaranteed health and eternal salvation. Those pilgrims forced to abandon attempts at pushing through the crowds to the clothes had another option: they could hold up a mirror to capture the divine energy.

By 1432, Gutenberg himself had seen the blacksmiths of Aachen make a fortune selling these metal mirrors, and long before the pilgrimage had ended, everything was sold out.

Gutenberg intended to mass produce mirrors, 32,000 in total, and sell them for half a guilder each. This would yield a total profit of around 15,400 guilders, many millions in today's money, as the cost of raw materials and moulds would amount to around 600 guilders.

"Either the Pope must abolish knowledge and printing or printing must at length root him out."
John Foxe, English author, 1563

No one had ever produced mirrors on such a large scale before, but in 1438, bad news arrived: due to fears of a plague epidemic, the pilgrimage was postponed, and Gutenberg was left with thousands of mirrors. For Gutenberg, however, the failed venture had still been valuable; he'd gained hands-on experience in developing technology for mass production and, most importantly, was now an expert in various moulding techniques.



POLFOTO/ULLSTEIN BILD

Gutenberg's house in Eltville, north-east of Mainz, still stands today.

Trial revealed secret project

In Strasbourg, Johann Gutenberg had long since gained a reputation as an enterprising man juggling numerous projects in addition to the failed production of mirrors. One scheme was so secret that only his business partners and a few assistants knew about it.

After one of the partners, Andreas Dritzehn, died in 1439, bits and pieces about the nature of Gutenberg's project were revealed to the public. This happened in a court case in December 1439, in which Dritzehn's family claimed back the money he'd invested in Gutenberg's business. The case file mentions lead, a press, various moulds, plus what one of the witnesses referred to as "the pressing".

The judgement stated that Dritzehn's heirs would receive a nominal amount, but that Gutenberg could keep the objects

Handwriting battled printing for 1,100 years

For more than a millennium, the use of type and ink was the preserve of professional workshops. It wasn't until the invention of the typewriter in 1868 that printing came into private homes.

750

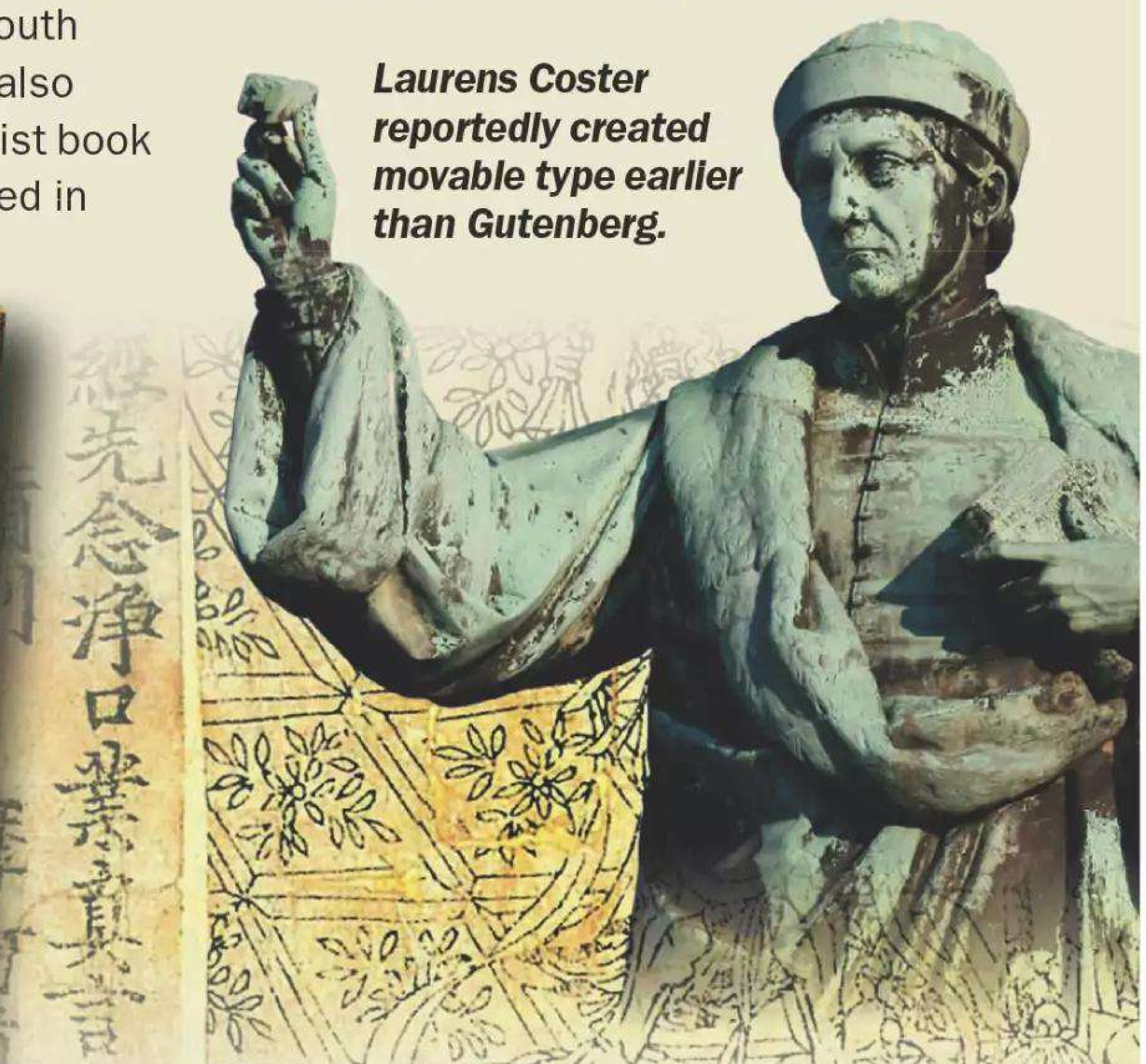
Koreans print block books

From the mid-eighth century, the Koreans print books as bound sheets, printed page by page with carved and coloured wooden plates. Today, these books are called block books.

Chinese were 400 years quicker

Long before Gutenberg had his bright idea in Europe, a Chinese man was thinking along the same lines. But the thousands of characters in the Chinese alphabet prevented the invention from catching on in the Middle Kingdom.

Around 1050, Chinese artisan Bi Sheng experimented with movable type – centuries before Gutenberg. The only thing historians know about Sheng is his name and that he cut characters out of clay blocks. The invention was almost useless because each Chinese character represents a word or phrase. As a result, Bi Sheng had to mould up to 5,000 types before he could print an entire book, so movable type didn't catch on. The Chinese had to use the woodblock technique, which was developed in Korea in the mid-eighth century. In 1966, researchers found a Buddhist textbook from the year 751 in a pagoda in South Korea. The Chinese were also early adopters: the Buddhist book *Diamond Sutra* was printed in 868. It wasn't until almost 700 years later that Europe began to catch up. A Dutch man reportedly experimented with type and ink in the 1420s – 30 years before Gutenberg. Laurens Coster cut type from bark and invented an ink that didn't run. However, there is no evidence to support the claim.



Laurens Coster reportedly created movable type earlier than Gutenberg.

Chinese printers knew the principle of movable type, but the 5,000 characters needed made it impractical. Instead, they carved entire pages into wooden blocks.

OSPREY PUBLISHING & SHUTTERSTOCK

in question and so continue working on the project without constraints. Like the mirrors, this project was about mass production – but no one outside of Gutenberg's inner circle had the imagination to think what it might be.

Gutenberg was almost unknown

Johann was born under his father's name Gensfleisch in Mainz around 1400 but switched his name to 'von Gutenberg' (after a family estate) upon reaching adulthood. Around 1434, he left his hometown to escape the economic and political strife that raged between craftsmen and the old bourgeois families that threatened to ruin him. In voluntary exile, he settled on the outskirts of Strasbourg.

Gutenberg remained in Strasbourg until 1448. There he was engaged in goldsmithing, coinage and the production of religious mirrors. Historians know virtually nothing about his private life at this time – only that he came from a good family, was in his 30s and ambitious, kept a large house and had a taste for wine.

Documents from July 1439 show that he paid tax on a store of 1,500 litres. This was enough to furnish a household of around 10 people – including ▶

1050

Chinese mould movable type in clay

Around the year 1050, the Chinese make movable type from fired clay. The inverted characters are blackened and used for printing. Once all impressions are taken, the type can be reused.

1234

Koreans cast movable type in bronze

Korean Choe Yun-ui produces the earliest known metal movable type. The oldest existing book printed with metal type is the Buddhist scripture *Jikji* from 1377.

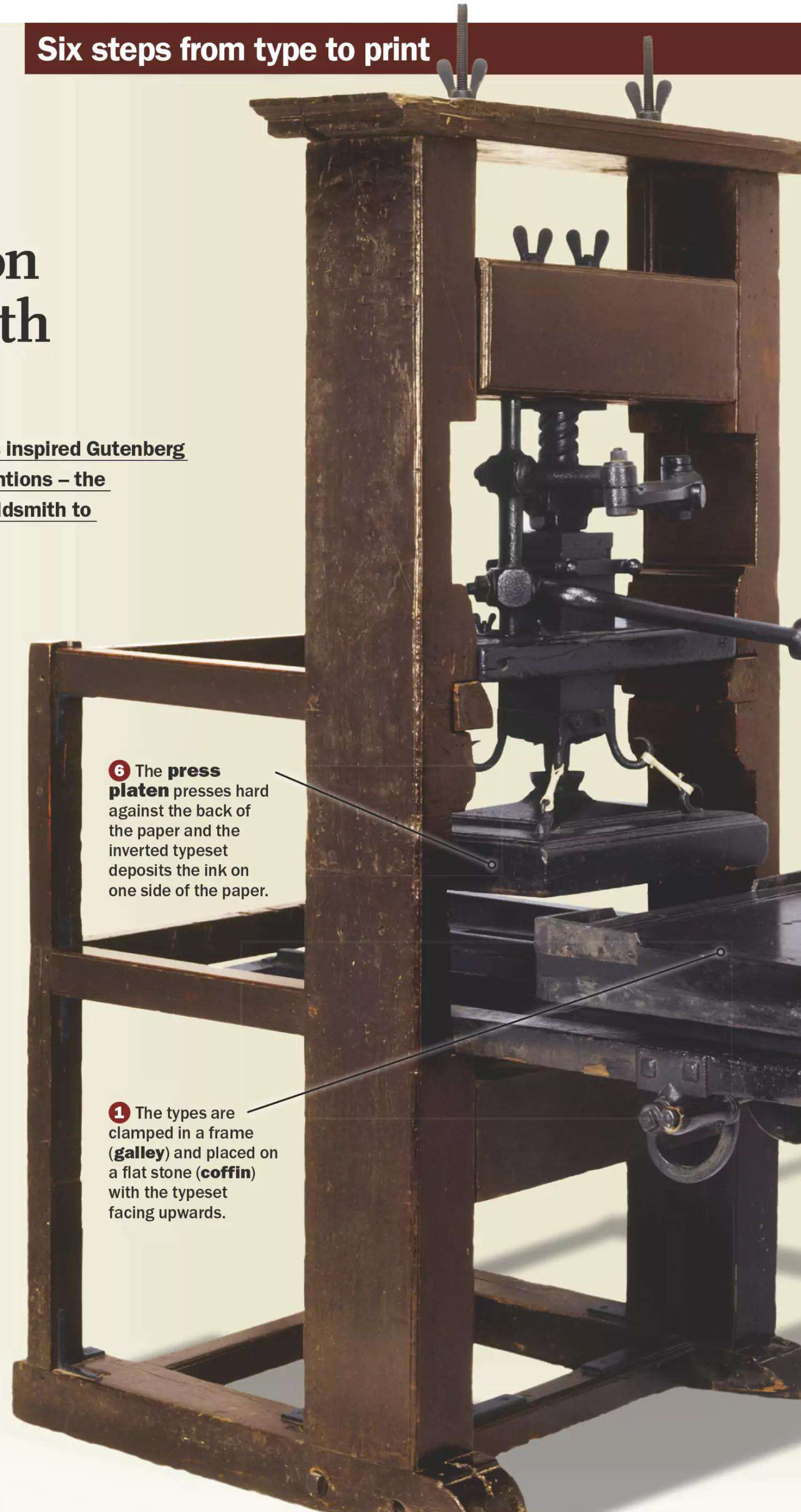
Choe Yun-ui's bronzes date from 1234. No one knows what he printed.

1454

Gutenberg built on old knowledge with new genius

In 1454, the winemakers' ancient grape press inspired Gutenberg to create one of history's most important inventions – the printing press. He used his knowledge as a goldsmith to quickly and cheaply cast type in metal.

Six steps from type to print



For 400 years, printers used printing presses based on Gutenberg's principle. It wasn't until the 19th century that the process became automated.

DORLING KINDERSLEY

Type was inspired

Gutenberg cast type in tin, lead and the metal antimony (stibium in Latin).

DORLING KINDERSLEY

Movable type was the heart of Gutenberg's invention. Each type was an inverted metal profile of a single letter or character. When inked, the type acted exactly like a stamp that, under pressure, deposited the character on to a piece of paper. The type could be included in any word or sentence, and so could be reused repeatedly elsewhere.

Gutenberg was a trained goldsmith and used his expertise to develop a method of producing type quickly and cheaply. With a precision of 0.01 mm, he could cut a letter out of the end of a metal rod. He then used a hammer to strike the rod hard against a piece of copper, which formed the base of a hand mould. After that, he was soon producing large quantities of movable type characters. No one had done this before Gutenberg.

BRIDGEMAN

The handle on Gutenberg's printing press was attached directly to the screw.

GETTY IMAGES

Gutenberg's typefaces produced consistently perfect impressions.

housekeeper, servants and assistants, which suggests he was happy to pay for everyone's drink. This meant the supplies in Gutenberg's wine cellar were sufficient for a daily ration of about half a litre per person, which was usually diluted.

No documents reveal whether he had a wife and children. In any case, Gutenberg was surprised when a local woman, Ennelin, accused him of breaking a promise of marriage in 1436. When he didn't keep his word, Ennelin's mother, Ellewibel, took him to court and demanded compensation. No one knows if Gutenberg was forced to pay up. The text of the judgement has not been preserved.

Stroke of genius took shape

Unmarried and determined, Gutenberg continued his mysterious experiments in his workshop in Strasbourg, but in 1448, for reasons unknown, he packed up all his equipment and moved to Eltville, north of Mainz. There he borrowed 150 guilders from a cousin to finance setting up a printing house, hire staff and acquire the tools and equipment needed to realise his grand dream.

However, money was tight, so in 1449 Gutenberg entered a partnership with wealthy businessman Johann Fust, who lent him 800 guilders – around £100,000 or $150,000 in today's money. With the extra money, Gutenberg was soon able to set up his printing press – complete with the inventions he had spent years working on.

Inspired by a wine press, Gutenberg had built a wooden printing press, the centrepiece of the entire print shop and the place where book pages would be duplicated. But the most groundbreaking of his inventions was the hand mould, which enabled him ▶

Readers wanted embellishments

Before Gutenberg's invention, handwritten books were elaborately embellished with brightly coloured engravings, patterns and drawings of flowers, animals and characters from the story. Readers expected impressive decoration in their books, so Gutenberg had to hire traditional scribes and illustrators.

SCANPIX/AKG-IMAGES

1461

First illustrated book

German Ulrich Boner publishes *Edelstein*. For the first time, a book printed with movable type also contains printed illustrations. The book contains a collection of fables and is printed by Albrecht Pfister in Bamberg, Bavaria.

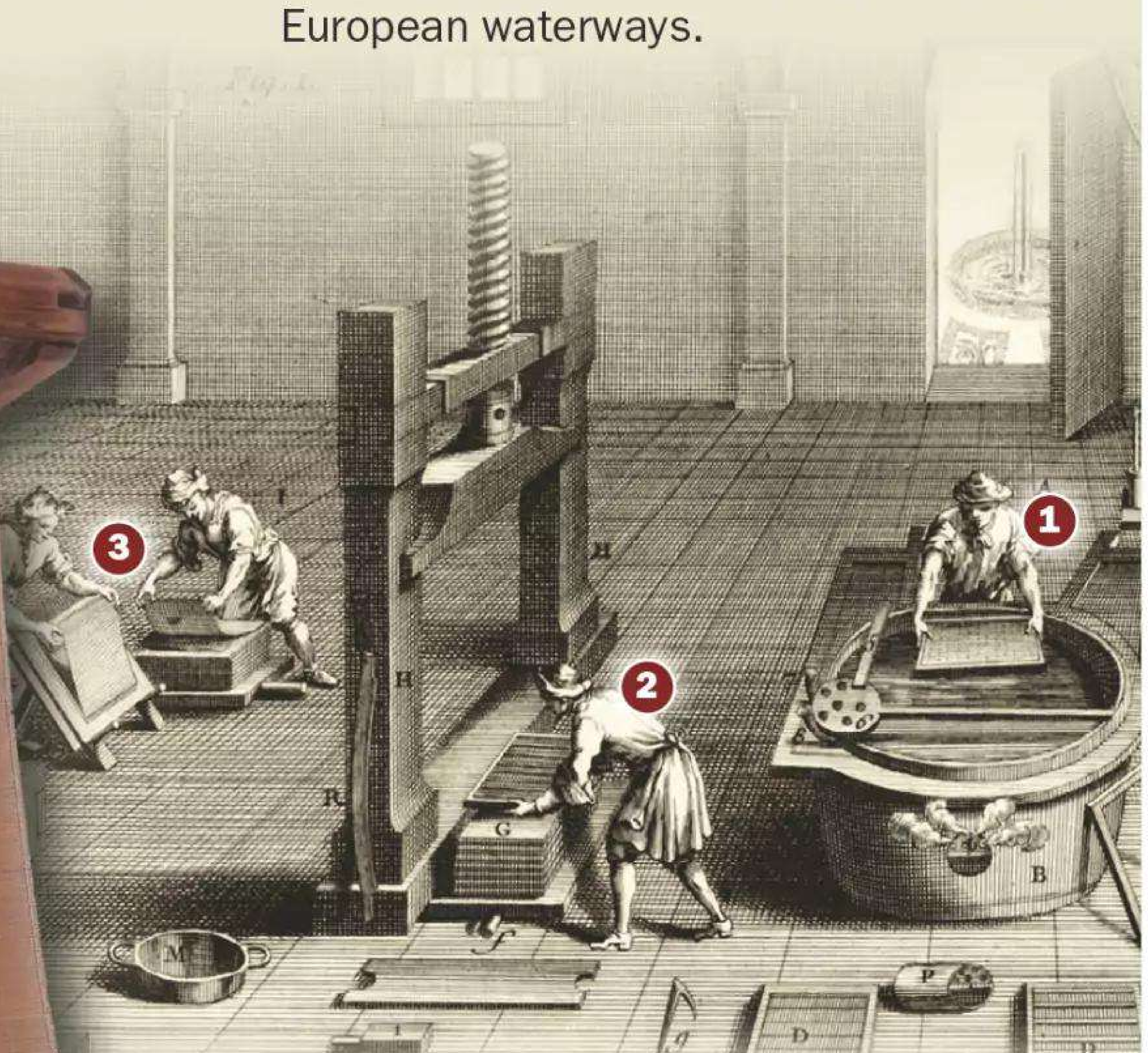
Paper was Chinese state secret

In AD 105, the first sheet of paper was made at the Chinese court. The recipe only became known beyond the empire's borders when a few Chinese prisoners of war blabbed 700 years later.

Before paper was invented, the Chinese wrote on silk, which was extremely expensive to produce. Eunuch and court official Ts'ai Lun solved the problem in AD 105. He soaked bark, old cotton rags and hemp until the ingredients were transformed into a consistent fibrous soup. Ts'ai Lun then placed the pulp in frames and squeezed it using large screw clamps to drain the water. The individual sheets of paper became flat and thin.

Paper had two advantages: it was easier to write on than silk and its ingredients were cheaper. Emperor Hedi realised its value. Now he could profit from selling that silk for clothing. No one was allowed to pass on the recipe, and for centuries China's emperors persecuted anyone who tried to break their monopoly. Despite the ban, however, the recipe slowly migrated westwards. Six hundred years later, it reached the great trading city of Samarkand in present-day Uzbekistan via the Silk Road. Only after a Muslim invasion of the city in the early eighth century did a few Chinese prisoners of war speak of it. But it took another 500 years for paper mills to spring up along European waterways.

The paper mould is filled with wet pulp. The frame holds the mesh in place while the water is forced through it.



***1* The papermaker dips his mould into the vat of wet pulp, dissolved rags or bark and *2* places it in the press. *3* The water drains out and after drying, the sheet of paper is finished.**

to quickly produce individual letters from metal in "movable type", which were assembled into text to be reused for print after print.

To top it off, he had created a thick, linseed oil-based printing ink that, unlike water-based inks, was characterised by its ability to adhere to the type, making the printed text appear clear and smudge-free.

Initially, Gutenberg started printing indulgences, schoolbooks, calendars and other small prints for the Catholic Church to provide him with an income. And the Church was excited about this new cheap technology.

Gutenberg wanted a masterpiece

As he became proficient with the new technology, a grand plan began to form in Gutenberg's mind. The former goldsmith tinkered with the idea of printing a Bible, a surefire bestseller, but also an overwhelming task for the first man who could boast the job title of 'printer'.

The Bibles already on the market were all handwritten gems, and if Gutenberg hoped to get a foot in the

1464

Printers move to Venice

Several German printers settle in Venice. In a short time, the canal city supplants Mainz as the capital of printing. Printers compete to produce beautiful books with exquisite illustrations.

1468 †

Johann Gutenberg dies

Gutenberg dies and is buried at the Franciscan Church in Mainz. He was virtually unknown at the time, and when the church was destroyed a few years later, his grave was lost.

1500

Book sales boom

Only five decades after Gutenberg's invention, over 10 million books have been printed across 40,000 titles. That's about one book for every five Europeans.

Protestants printed propaganda calling the Pope nothing less than "antichrist".

SCANPIX/AKG-IMAGES

door of his customer base – mainly monasteries and churches – his work had to surpass the handmade ones in splendour and quality. In short, he had to create a masterpiece.

And a masterpiece it was. In the autumn of 1454, after two years of hard labour, Johann Gutenberg and his assistants had printed 180 Bibles with a total of over 230,000 pages. A gigantic achievement and a formidable innovation at a time when it could take a scribe five to ten years to produce just one copy of the Bible.

At a large market in Frankfurt in early 1455, printed books were seen by a wider audience for the first time. Rows of identical Bibles were offered for sale. They were an astonishing sight for the visitors who gazed in awe at the beautiful works.

From then on, things took off. Word of Gutenberg's revolutionary printing spread like wildfire through Europe, and on 12th March 1455, Bishop Enea Silvio Piccolomini – later Pope Pius II – wrote a letter to his superior, Cardinal Juan de Carvajal:

"Of that extraordinary man seen in Frankfurt, nothing false has been written to me… [The script is] written in extremely elegant and correct letters, without error, which Your Eminence could read with no difficulty and without glasses."

If Piccolomini had known what Gutenberg's invention would lead to, he would likely not have referred to him in such laudatory terms.

Theses crushed Vatican's

On 31st October 1517, just 63 years after Gutenberg printed his first text, German Augustinian monk Martin Luther had become so dissatisfied with the Catholic Church's abuse of power that he wrote and published 95 provocative thoughts about the Church. Among other things, Luther rejected the idea that the Pope could forgive sins – only God could.

Luther also believed that the Pope should have known about the poor morals of the sellers of indulgences, "for then he would know that St Peter's was built with the skins, bodies and bones of his flock".

"Of that extraordinary man seen in Frankfurt, nothing false has been written to me."

Silvio Piccolomini, Italian bishop

Luther didn't just strike at the heart of popular discontent. Millions of Europeans bought his books and pamphlets with texts that thundered against the Vatican. Without the printing press, he would never have been heard.

Over the next 100 years, churches across Northern Europe broke with the Vatican and embraced the Lutheran faith. Europe had been split in two.

The 550-year-old Bible was the world's most expensive book.

Masterpiece sold for $5.4 million

Gutenberg's first book was a two-volume Latin Bible with 1,282 pages, each with two columns and 42 lines of text, printed from 290 different movable typefaces.

The Bible was a semi-finished product that was completed by scribes. They decorated the pages with colourful initials, flower vines and drawings, so no two copies were identical.

The Bible was printed on both handmade paper and parchment with 135 and 45 copies made respectively. In total, 48 copies are preserved – most are incomplete.

Historians estimate that 20 men were involved in the task. Gutenberg probably used six printing presses.

The Bible was probably so expensive that only churches and monasteries could afford it. In 1987, a Japanese man bought a copy through Christie's auction house for $5.4 million – the most expensive printed book ever.

1799

Mass production of paper

Frenchman Nicolas Louis Robert patents the first paper machine capable of producing a continuous stream of paper. This makes it possible to produce paper on a large scale.

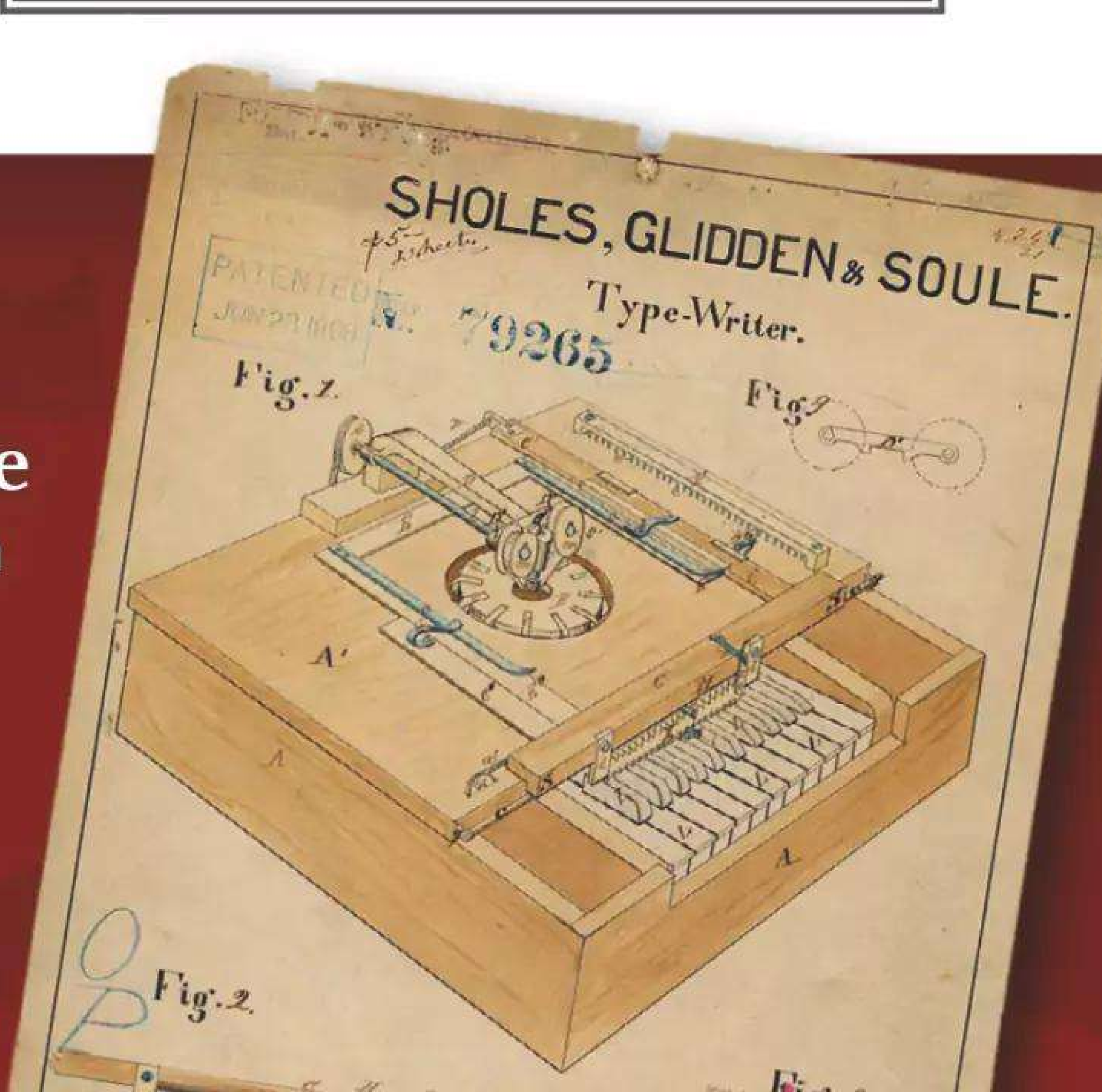
1868

Typewriters become commonplace

In 1868, American Christopher Sholes receives a patent for the first practical typewriter. Now individuals can type much faster than write.

In 1873, inventor Sholes signed a contract with gun manufacturer E Remington and Sons, which subsequently became a typewriter manufacturer.

NATIONAL ARCHIVES



SORCERERS CREATED MODERN SCIENCE

For more than 2,000 years, alchemists dissolved, boiled and vaporised everything from blood and urine to eggs and mercury in their gloomy workshops. Their dream of gold and eternal life remained just a fantasy, but instead, alchemists discovered several elements and laid the foundations for modern chemistry and medicine.

In 1669, German alchemist Hennig Brand discovered a white substance that glowed in the dark. Without realising it, he had found the element phosphorus while heating urine in a glass flask.

MARY EVANS & SCANPIX/AKG-IMAGES & SHUTTERSTOCK

Monk had keys to eternal life

WELLCOME IMAGES

In the 15th century, the monk Basil Valentine published ***The Twelve Keys***, a handbook for alchemists. Its drawings are so symbol-laden that, to the untrained eye, they are incomprehensible. And that was the intention – only true alchemists could interpret the illustrations.

See the drawings ➤

BY ERIK BORK

With a triumphant flourish, chemist James Price opened his crucible and took out a small nugget of the purest gold.

A gasp went through the distinguished audience. They were now each allowed to touch the lump of metal and quickly realised that they had just witnessed a miracle.

The display was the culmination of James Price's career. During the summer of 1782, word had spread in London that the promising young scientist had succeeded in turning mercury into gold.

Several prominent theologians, two masters of gold refining and a handful of members of the House of Lords had now also been convinced. During the process, they had closely followed Price's every move, and even Lord Palmerston, Commissioner of the Treasury, had been allowed to weigh the mysterious red powder that was sprinkled on the mercury – which, according to Price, was part of the secret of turning it into gold.

Religion and knowledge mixed

With his red powder, mercury and hot crucible, James Price used all the traditions of the ancient art of alchemy – often aimed at creating gold or achieving eternal life. For millennia, men and women had toiled in the flames, cooking hair, excrement, saliva, copper and more, invoking the help of the gods in the hope of eventually producing the precious gold.

The first alchemists, who laid the foundations of the European alchemical tradition, can be traced back to the city of Alexandria a few hundred years before the birth of Christ. On the shores of the Mediterranean, the great city was a buzzing metropolis, where Roman culture blended with Egyptian traditions and Jewish religion. Outside the city towered the 60-metre-high lighthouse of Pharos – one of the Seven Wonders of the World – and inside Alexandria, the world's largest library made the city a centre of learning for the entire Mediterranean region. In this setting, alchemists could embrace the free-flowing beliefs and blend them with the science of the day.

The first texts on alchemy mention legendary figures such as Mary the Jewess and a man named Democritus, who both experimented with alchemy. Historians know very little about these people, but Democritus supposedly acquired his alchemical skills through a divine revelation. He began mixing copper, mercury, arsenic, sulphur and zinc oxide to achieve everything from a purer mind to gold.

World consisted of four elements

The first alchemists were inspired by the Greek philosopher Aristotle, who believed that everything was comprised of earth, air, fire and water in varying proportions. To prove the theory, alchemists simply needed to take a piece of wood and place it in the flames.

As the wood heated up, water began to drip from its veins – therefore wood contained water, the

EIGHTH CENTURY
Middle Eastern alchemists took over from the first European alchemists and discovered elements such as antimony.
SCIENCE PHOTO LIBRARY

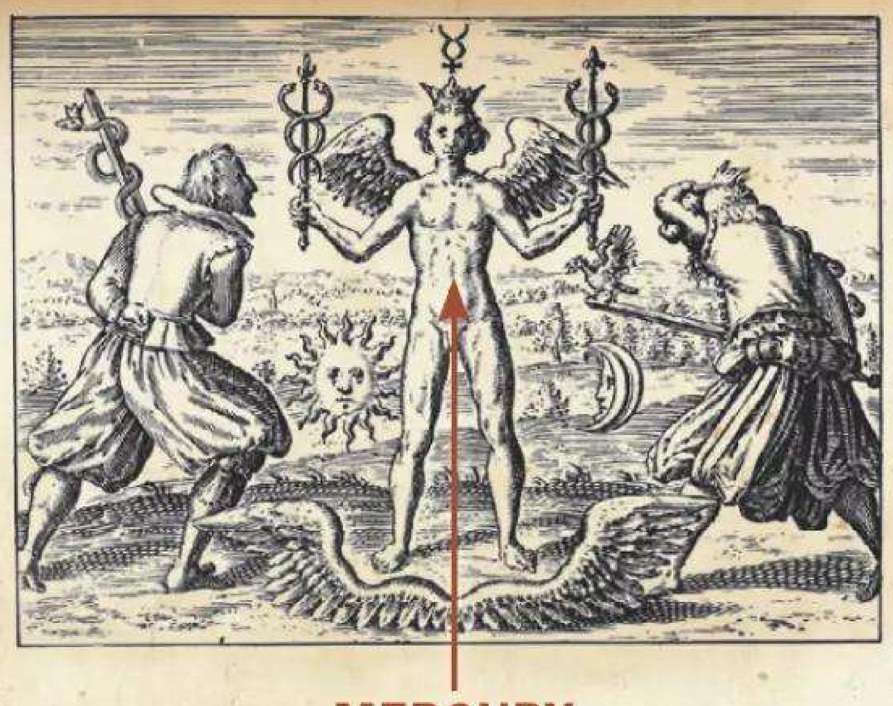
POLFOTO/TOPFOTO & JUPITER IMAGES

KEY 1

The drawing shows how gold (the king) can be cleaned of silver residue (the queen). The gold is mixed with antimony (the wolf) and heated in a crucible to remove the silver. The three flowers indicate that the process must be done three times.

KEY 2

The key tells how mercury (naked man) can be purified. The man on the left symbolises the transformation of liquid into solid (the snake on his sword), while the other symbolises evaporation (the flying eagle on the sword).



alchemists concluded. Soon after, the wood began to smoke – therefore it contained air – and finally, the wood ignited, so it must also contain fire. When the fire had burned long enough, the wood turned to ash – a kind of soil. And with that, the circle was complete and the theory proven.

At the same time, alchemists believed that all materials had a divine aspiration towards greater perfection. The art of alchemy consisted of helping copper or mercury become gold by changing their composition of earth, air, fire and water.

Gold was divine

It was no coincidence that gold became the target of alchemists' endeavours. Long before the first gold coins were minted in the city-state of Lydia in Asia Minor in the sixth century BC, the pharaohs mined gold from the sands of the Nile. Gold was beautiful and sparkling, and even very early cultures attributed divine properties to it when they found it in nature. The glittering metal was like grains of sunshine, and whoever owned gold possessed a part of the sun, the main source of life.

It was therefore natural that the alchemists around Alexandria also sought gold. However, their work and knowledge came to an abrupt halt when the library of Alexandria burned down in 47 BC and its approximately 500,000 scrolls either went up in smoke or were lost when Egypt was conquered by the Romans in 30 BC.

What the Europeans lost was picked up by the Arabs, and by the late eighth century AD, Baghdad had become the centre of chemical experimentation. The city was a glittering oasis of palaces and lush gardens, and on the banks of the Tigris River walked Abu Musa Jabir ibn Hayyan al-Azdi – known in the West as Geber. He was the caliph's court physician and had acquired great knowledge in most disciplines, from astronomy and music to philosophy, geology and alchemy.

Geber was a practical man who believed that all knowledge should be tested by experimentation. His laboratory was equipped with furnaces, funnels, filters and flasks, and the entire place buzzed and bubbled as Geber devised new experiments. He acknowledged Aristotle's theory of earth, fire, air and water, but refined many of the theories and performed far more experiments than the first alchemists.

By mixing vitriol with alum and saltpetre, Geber discovered nitric acid and was the first to isolate and describe elements such as antimony and bismuth. He also discovered the poisonous substance arsenic by heating a toxic mineral. Geber used some of these substances as rust inhibitors or to treat leather and cloth.

Geber had high expectations for his experiments. In addition to gold, he dreamed of creating snakes, scorpions and humans in his crucibles and flasks. The hard-working scientist succeeded in none of these endeavours. When Harun al-Rashid became caliph, Geber was caught up in the power struggle. Despite his great achievements, he was exiled and declared an enemy of the state.

With his use of experiments, Geber was still considered the greatest alchemist of his time and inspired practical experimentation for hundreds of years to come.

Knights brought alchemy to Europe

The recipes and descriptions of Geber and other Arab alchemists were brought back by the Crusaders when they returned to Europe from the Middle East in the 13th ▶

Wanted: philosopher's stone

Alchemists dreamt of getting their hands on the philosopher's stone, which could reward its owner with gold, eternal life and infinite wisdom.

For centuries, alchemists searched for the philosopher's stone, said to turn all metals into gold and postpone death.

The idea of magic stones probably originated in eighth-century Baghdad, where the alchemist Geber believed that one metal could be transformed into another using a substance called *al-iksir* – hence the word elixir. The substance was described as a powder made from a mysterious stone. According to alchemists such as Sir Isaac Newton, the concept of the philosopher's stone should not be taken literally, but as a spiritual state that gives the alchemist infinite insight.

Several men claimed to own the stone – without letting anyone see it.

Some claimed the philosopher's stone was a magical stone, others said it was a spiritual state.

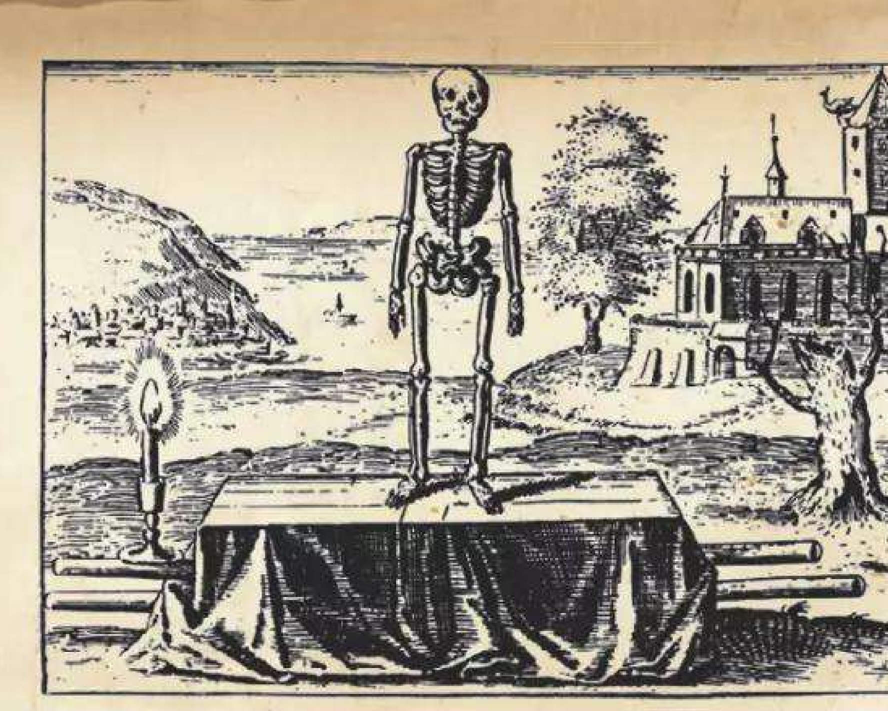
POLFOTO/TOPFOTO

KEY 3

The meaning of this key is unclear – as is that of the dragon in the foreground. According to some alchemists, the fox and two chickens in the background symbolise how different substances can change from liquid to solid and vice versa.

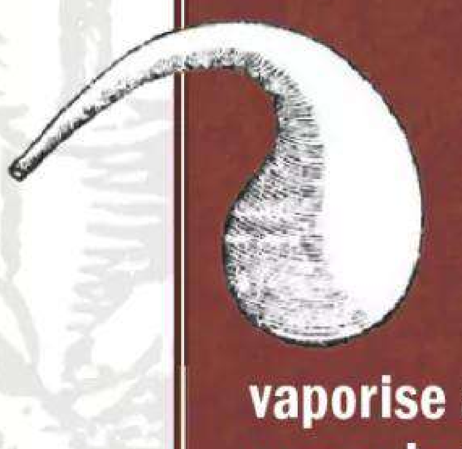
KEY 4

The drawing explains how substances must be purified before they can be used in gold production. The image refers to the chemical process of fermentation, where organic material is broken down into another material.

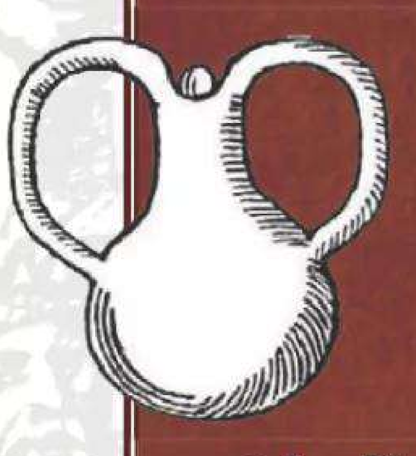


Alchemist's toolbox

Many of the tools that scientists still use in modern laboratories were invented by alchemists hundreds of years ago.

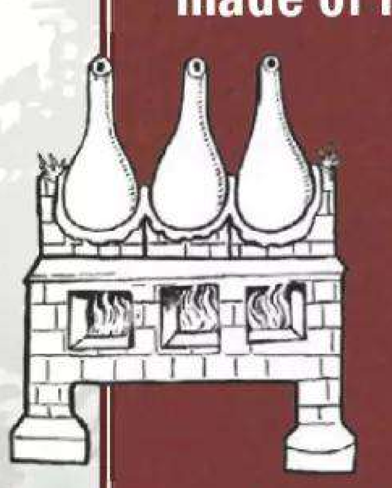


THE RETORT is a flask for separating substances (distillation). A mixture is heated in the flask and because substances vaporise at different temperatures, one substance evaporates and condenses in the neck. It can then be collected at the end of the neck.



THE PELICAN is used to re-distil liquids. The vapour from the liquid is condensed in the arms and runs back into the main chamber to be distilled again. The process is used if the boiling points of substances are close to each other.

THE CRUCIBLE was one of the most important tools, used to melt metals. The Hessian crucible was developed in Hesse, Germany, and only recently have scholars discovered why it could withstand so much heat – in part because it was made of heat-resistant minerals.



A SAND BATH is a method of achieving uniform heat around a flask. The sand is heated and the flask containing liquid is placed on top. The method is still used today for simple scientific experiments.

century. However, it would be another couple of hundred years before alchemy really took hold in Europe. After centuries of the Church setting the scientific agenda, a sense of renewal and rebirth washed over the European continent, and art, religion and science underwent enormous changes.

The learned Europeans of the Renaissance began to put themselves, instead of God, at the centre of everything, and the new world view fitted well with alchemy, where anyone could perhaps create their own wealth by simply sprinkling a little mercury into a box.

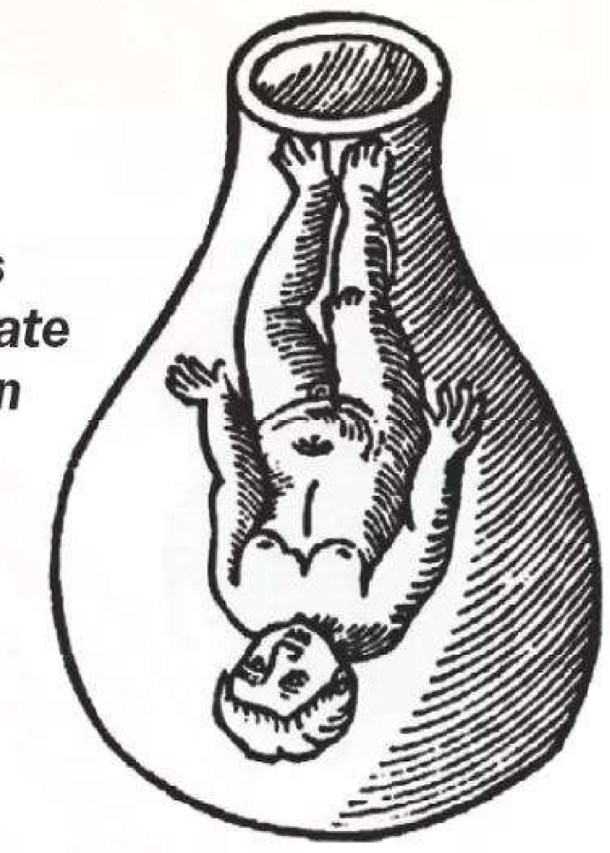
Puffers took over

Furnaces and bellows popped up in attics and cramped cellars everywhere during the 16th and 17th centuries, when even ordinary men – and women – threw themselves into the hunt for gold. Their vigorous use of bellows earned them the nickname puffers, but learned alchemists had little time for them.

"False alchemists seek only to make gold; true philosophers desire only knowledge. The former produce mere tinctures, sophistries, ineptitudes; the latter enquire after the principles of things," one of the scholars wrote.

The princes and kings of Europe were also interested in alchemy and paid huge salaries to their own teams of puffers. The rulers were not interested in alchemy because of the "principles of things", but hoped that their hirelings would one day create gold, giving them even more power and wealth.

One of these was the French king Henry IV, who employed several alchemists. The overall goal was to create gold, but his alchemists also worked to revive plants that had been



Alchemist Paracelsus believed he could create artificial humans in an airtight container – using semen and horse manure.

burned – in the hope that the king could be resurrected after Judgement Day.

Another king with a penchant for alchemists was Scotland's James IV, who was so generous with his money that alchemists from all over Europe crowded the castle gates.

James, however, pinned his hopes on a French doctor called John Damian, who in 1501 was hired as chief alchemist to oversee the castle's many smelting furnaces. Damian was happy to take on the job, because in addition to a princely salary, he was provided with every imaginable comfort, including lambskin-lined robes and a tapestry-covered four-poster bed.

In the evenings, he acted as the king's card partner, and during the day Damian kept the furnaces constantly melting metals – without ever managing to produce a single piece of gold for James IV.

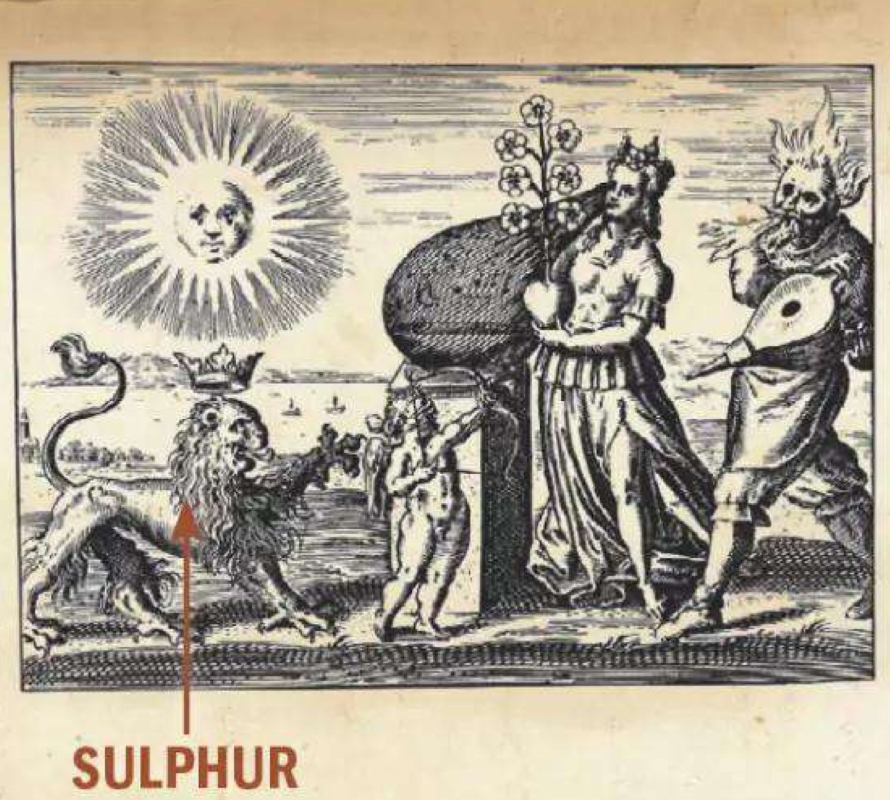
Yet the king's faith never wavered – not even when Damian claimed he could fly to France. He threw himself over the ramparts wearing a pair of homemade wings constructed from chicken feathers, but instead of flying, John Damian ended up with a broken leg.

Medicine and alchemy

Far more important to alchemy and science was the Swiss Paracelsus. Throughout the 16th century, he trained as a doctor and then travelled

KEY 5

This very complex drawing symbolises the process of dissolution, where different substances are mixed. The lion represents sulphur, while the black mass from the woman's eyes and mouth symbolises the ability to think and visualise.



KEY 6

The overall theme of the drawing is that different chemical substances can be mixed into new substances. The process is shown both through the marriage of a king and a queen, and by the Sun and Moon, which are connected by a rainbow.

around most of Europe teaching medicine and alchemy.

Paracelsus was convinced that physical health depended on harmony between nature and the inner man – and any imbalance could be corrected through chemistry. In doing so, Paracelsus expanded the concept of alchemy for the first time to include an early form of pharmaceutical science.

"Many have said of alchemy that it is for the making of gold and silver. For me such is not the aim, but to consider only what virtue and power may lie in medicine," wrote the Swiss alchemist.

Instead of pouring sulphur, mercury, iron and other substances into the flames, Paracelsus mixed the ingredients together and poured them into his patients' mouths. In this way, he believed he had found a cure for the dreaded disease syphilis, while by using an extract from poppies, he also invented a painkiller.

However, Paracelsus was far from a scientist in the modern sense. Like Geber in eighth-century Baghdad, he was also convinced that he could create an artificial human being in a laboratory.

The recipe called for human semen to be placed in an airtight container with horse manure for 40 days, after which the result would be exposed to magnetism. At this point, a living homunculus – a very small human being – would already be visible, which would then be fed human blood for 40 weeks to become a perfect human child.

Paracelsus's earthly life ended abruptly in Salzburg in 1541. Cruel tongues claimed that he had fallen down a staircase while in a drunken stupor, while others believed that the alchemist had finally created an elixir of life and was now forever wandering the roads of Europe.

Recipes written in code

Although Paracelsus and his followers began experimenting with the effects of chemistry on humans, they left very few concrete instructions to document their painstaking work.

Instead, alchemical writers had a strong tradition of veiling their descriptions and recipes under a layer of symbols and metaphors, and many of the writings are so unintelligible and ambiguous that they remain mysteries.

One of the most famous examples is the *Mutus Liber (Mute Book)* from 1677, which is believed to provide through 15 illustrations a recipe for the philosopher's stone, which can turn other metals into gold. The pictures – created by French apothecary Isaac Baulot – feature winged angels, burning people and mysterious animals, while alchemists distil dew ▶

16TH CENTURY Several European kings took an interest in alchemy and employed large teams of alchemists to find the recipe for gold.

GETTY IMAGES

KEY 7

The drawing is heavily laden with symbols and shows an alchemical mandala in which the square represents the four elements of earth, fire, air and water, while the triangle refers to Paracelsus's three elements: salt, sulphur and mercury. The double circle symbolises the earthly and heavenly spheres, between which chaos reigns.

KEY 8

This symbolises fermentation. The theme is resurrection, and the man sowing the field indicates that new substances are born when old ones decompose. This is also evidenced by the skeleton (death) resting its head on a sheaf (life).

or extract solar and lunar essences. The recipe for the last drawings, where the philosopher's stone is finally created, becomes quite cryptic, and the artist has made the series of images so incomprehensible that no one has yet solved the puzzle.

For alchemists, the complex language was designed to keep amateurs out, so that only the most persistent and true masters could gain insight into the incredible knowledge.

They believed that alchemy was not just about fire or molten metals. It was also a spiritual endeavour, where gold could ultimately come out of the fire, but could also come from an angel following the alchemist's work.

Knowledge did away with religion

However, the religious dimension slowly disappeared as the principles of modern science took shape during the 17th century. This was helped by the philosopher Francis Bacon, the mathematician and astronomer Sir Isaac Newton, and the Irish chemist and physicist Robert Boyle.

In particular, Boyle – considered the first modern chemist – played a significant role in the transition from the diffuse mysticism of alchemy to controlled experiments, because he eagerly pursued both.

In the mid-17th century, he developed an air pump, and by the light of day, the young Boyle sat hunched over his experiments, observing how the flame of a candle changed when he changed the pressure in his pump. The work was summarised in 1662 in Boyle's Law, which states that the product of pressure and volume is constant for ideal gases if the temperature is constant.

Boyle's highly precise experiments and methodical work caused a stir, and when he published his book *The Sceptical Chymist* in 1661, his writings resonated in scientific circles across Europe. In the book, the chemist rejected the existence of the ancient Greeks' four elements – earth, fire, air and water – and instead defined actual elements as primitive and simple bodies that can react with each other and form chemical compounds.

The idea was revolutionary and laid the entire foundation for modern science for the next few hundred years.

Geber inspired Boyle

However, Robert Boyle's work did not mean that traditional alchemy was put to rest. Like several other scientists of

Natural gold is cheaper

Time and time again, alchemists had to give up creating gold – with good reason, because artificial gold is expensive and difficult to create.

For millennia, alchemists have dreamed of creating gold with fire, flasks and crucibles. Today, scientists realise that the task is near-impossible because gold is an element. The creation of gold from other elements requires an elemental transmutation, which necessitates extreme amounts of energy.

In 1941, three scientists at Harvard University managed to bombard 400 grams of mercury with a storm of high-speed neutrons in a particle accelerator, after which they placed the irradiated sample in a vacuum. The result was three isotopes of gold – completely invisible to the human eye. The amount of gold increases slightly if, for example, platinum is irradiated with deuterium nuclei.

However, it makes no sense to create gold in this way because the method is so expensive that it would never be able to compete with naturally occurring gold.

Economically speaking, gold mining pays better than alchemy.

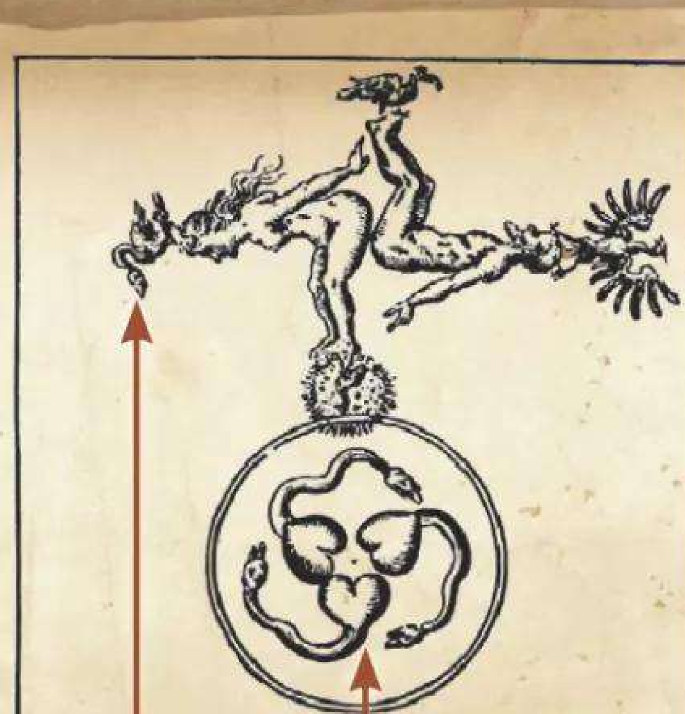
SHUTTERSTOCK

Robert Boyle founded modern chemistry – even though he was an alchemist and avid hunter of the philosopher's stone.

SCANPIX/PRINT COLLECTOR

KEY 9

The two people and the circle form the alchemical symbol for the Earth. The three snakes are a reference to Paracelsus's three elements – called *tria prima.* The birds symbolise different chemical processes. For example, the swan on the woman's head symbolises calcination, where a substance is heated until it is transformed.



KEY 10

The two circles stand for heavenly perfection. The triangle symbolises Paracelsus's elements. The three symbols at the tips of the triangle stand for gold, silver and mercury. The meaning of the Hebrew words is unclear, but they are probably small verses written in Kabbalistic codes.

his time, he worked simultaneously with both mysticism and science, and in a long series of documents, Boyle wrote of his own search for the philosopher's stone.

The notes surrounding this work are often written in codes that have only been deciphered in recent years. They show that Boyle looked all the way back to the work of Geber in the eighth century and very much mixed religious beliefs with science.

The German alchemist Hennig Brand, alongside his search for the philosopher's stone, also conducted scientific experiments with liquids mixed with various substances. In 1669, he heated the remains of boiled urine and discovered the element phosphorus.

Over time, the experiments became more and more systematic, and it paid off. The number of known elements was 13 at the end of the 17th century, while by the end of the 18th century the number had risen to 78. During the same period, more and more alchemists began to earn titles such as chemist, physicist or doctor.

For many traditional alchemists, the transition was a tough time, with the hope of creating gold and eternal life seeming more and more hopeless. This made it all the more tempting to cheat with the results, and in the 18th century, French chemist Geoffrey the Elder even wrote a catalogue of trickster techniques:

"They often used double-bottomed crucibles … lining the bottom with oxides of gold or silver, then covering it with an appropriate paste. They also sometimes made a hole in a lump of coal and poured gold or silver into it," he wrote.

Price drank poison

It is unknown what method the chemist James Price used when, in 1782, he tried to convince the upper classes in London that he had produced gold.

Lord Palmerston of the Treasury had barely left Price's laboratory before rumours of the sensational discovery began to spread. Now members of the Royal Society also wished to witness the 'miraculous' transformation.

At first, Price resisted, claiming that he had already exhausted his supply of the mysterious transforming powder and that his health could not withstand the rigours of making more gold.

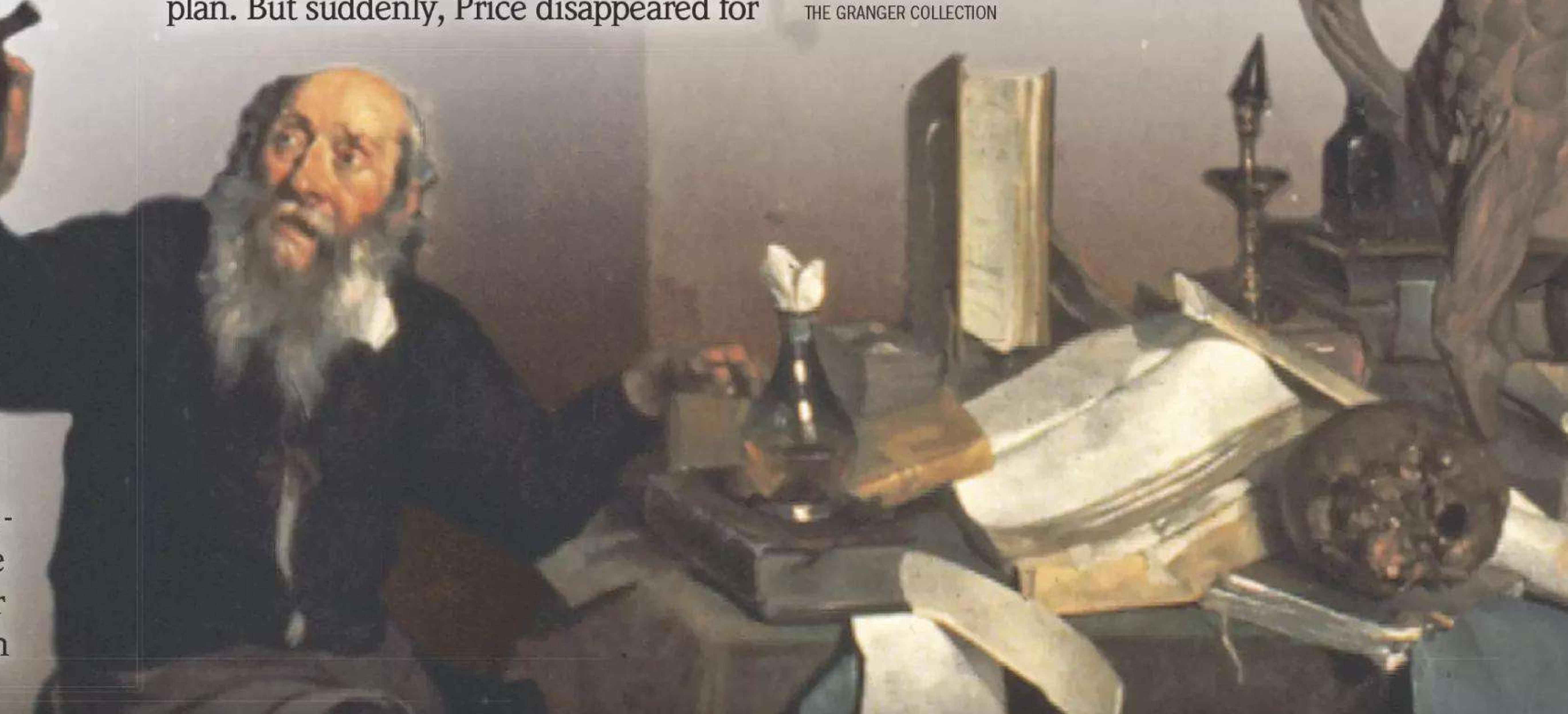
After threats of expulsion from the Royal Society, he reluctantly agreed. Soon after, the young scientist locked himself in his laboratory – apparently to make more of the red powder.

Six months later, Price re-emerged in public and invited the Royal Society to witness his gold production. The critical gentlemen took their seats in the public gallery and everything went according to plan. But suddenly, Price disappeared for a brief moment and then reappeared – now visibly dazed and confused.

For a few minutes, Price stumbled around in a daze before dropping dead between the flasks and crucibles. Instead of producing the mysterious red powder, Price had spent the last six months writing his will and concocting a deadly potion.

With James Price's tragic demise, the notion of creating gold with relatively simple means also died, and today many historians recognise Price as one of the world's last traditional alchemists. He probably didn't set out to be a con man, but like thousands before him, he dreamed of cracking the code of creation and making gold.

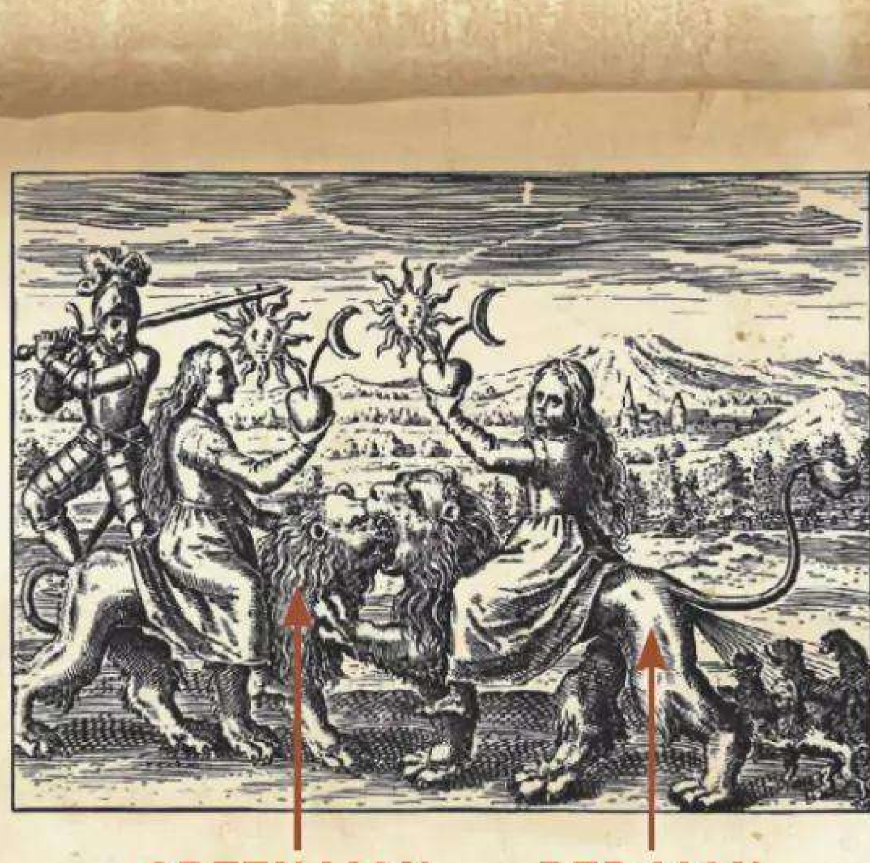
Even though the classical alchemists' final struggle for existence seemed desperate, they still achieved something of which they could be proud: in their dark cellars, the alchemists had laid the foundations of modern science.



18TH CENTURY
Alchemists were now taking a more scientific approach. They documented and conducted experiments under controlled conditions.
THE GRANGER COLLECTION

KEY 11

The drawing symbolises how the philosopher's stone can double itself. This alchemical process is called the nourishing of the red lion by the blood of the green lion. The process is illustrated by the lion on the right eating the lion on the left.



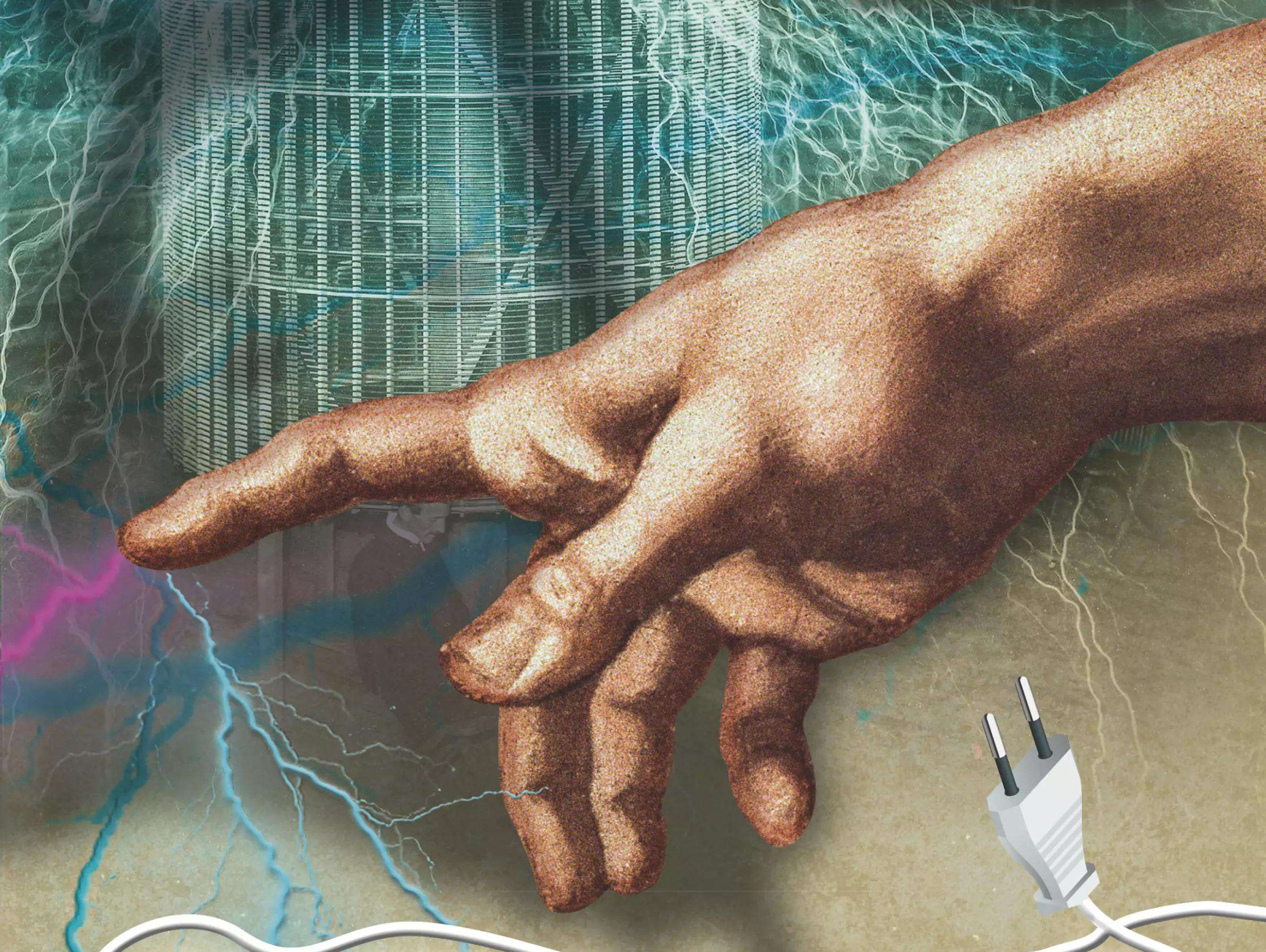
KEY 12

The lion and snake symbolise solids and liquids. The flowers connect this key with the first, in which the queen holds a flower. One of the flowers has been replaced with the symbol for mercury, meaning the process has reached its goal.

Search for mystifying spark

Light in a globe, power stored in a bottle and an artificial fish sewn from leather. Eighteenth-century scientists did everything they could to solve the mystery of electricity. It wasn't easy – it took 177 years before electricity could be controlled with a switch.

BRIDGEMAN, GETTY IMAGES & SHUTTERSTOCK



World/1705-1882

With the Enlightenment came the belief that man could use reason to explain everything that was previously thought to be God's creation. Scholars in Britain, the Netherlands, the USA and Denmark set out to prove that man could control the forces of nature.

From a weak current to a blazing sea of light

In 1882, the Edison Electric Light Company opened the world's first coal-fired power station in **London**, but the Central Electricity Board wasn't set up to create a national grid until 1926.

September 1882 saw inventor Thomas Edison open a power plant on the southern tip of Manhattan. The steam-run generator could power as many as **800 light bulbs**.

The 1973 oil crisis sparked interest in alternative energy. The Tvind schools in Denmark started building what was the **world's largest wind turbine** in 1975. Today, one turbine can supply 100,000 light bulbs.

BY KASPER SCHLIE & TORSTEN WEPER

The Royal Society in London is no ordinary organisation. Since 1660, this honourable society has brought together England's most curious scientists. Here they could study the mysteries of nature, formulate theories and test them via experimentation. Once a week, everyone gathered in the Society's auditorium to hear about their colleagues' latest discoveries and watch them perform experiments on the laws of nature.

Thirty-five-year-old Francis Hauksbee was put in charge of conducting the Royal Society's experiments. He was extremely resourceful and a skilful instrument maker, but due to his humble background as a cloth merchant, the other members didn't think much of him. One day in November 1705, he conducted an experiment that would astonish the distinguished gentlemen.

In front of a packed auditorium, Hauksbee poured a small amount of mercury into a glass globe, in which he created a vacuum using a pump he'd built himself. He then placed the globe on a stand so he could spin it using a crank. The room's candles were extinguished and when Hauksbee placed his hand on the globe's surface, an incredible thing happened: a flickering bluish light appeared behind the glass.

It was so bright that you could read a book in the darkened room. His colleagues were excited, even though no one knew how the light was created.

Hauksbee was the first person to create electric light, but he didn't understand what the discovery could be used for. He soon lost interest in electricity and concentrated on making money from his pumps.

Instead, other self-taught scientists took it upon themselves to solve the electrical mystery, but it wouldn't be easy. It would take 177 years before electricity could come out of a socket.

Francis Hauksbee (1660-1713)
Nationality: English
Discovery: Was first person to produce artificial light in an airless glass globe. The light was created by static electricity. Later, the machine was named after him.

BRIDGEMAN

Man-made electricity

The next breakthrough in the history of electricity came from cloth dyer Stephen Gray. He, too, had given up his old profession in favour of research. Wealthy friends had given Gray access to scientific papers, and through them the self-taught man educated himself.

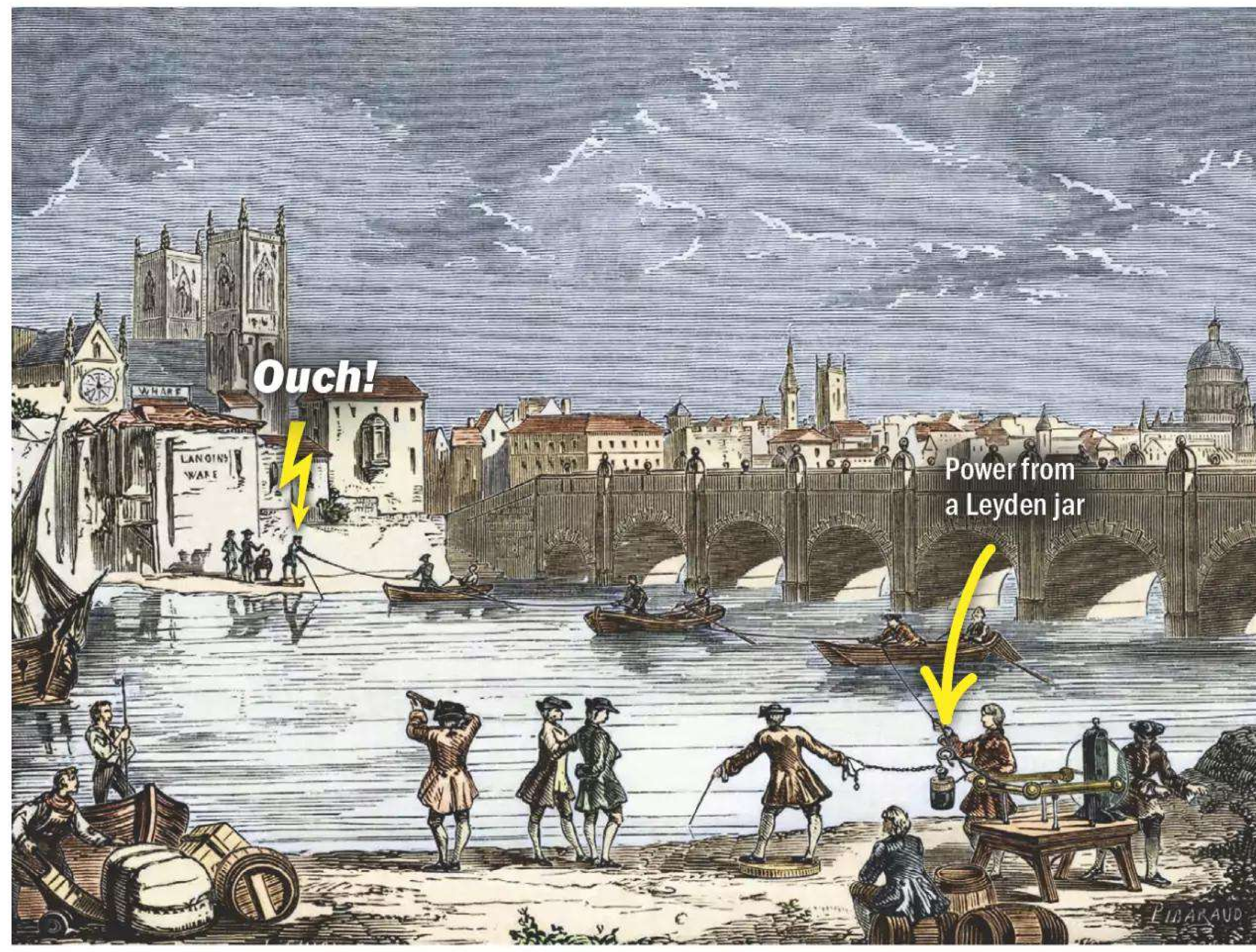
Late one night in 1729, Gray wondered why the electricity stayed inside Hauksbee's globe. Could it be coaxed out and used for something useful? As an experiment, he rubbed a long glass tube with a cork stopper at the end. The tube became electrically charged – but it was the cork that attracted dust and small pieces of paper.

"I was much surprised," Gray noted in his diary. "There was certainly an attractive virtue communicated to the cork by the excited tube."

When he stuck a wooden stick into the cork, the dust moved towards the stick, and the same happened when he placed a piece of ivory at the end of the stick.

Gray realised that electricity could move from one object to another. Later, he supported his theory with a spectacular experiment: using silk cords, Gray suspended a boy from a wooden stand so that he had no contact with the ground. Below him, Gray had strewn feathers and small pieces of gold leaf. Gray then rubbed a Hauksbee vacuum globe on the boy. A marvellous thing occurred: feathers and gold leaf lifted off the ground and clung to the boy's hands and face.

To onlookers it looked like magic, but through countless experiments, Gray came to understand what was going on: electric current could travel.



SPL/SCANPIX

In 1747, 25 members of the Royal Society conducted an ambitious experiment: they ran a wire under the Thames to see whether electricity could reach that far. It could.

Electrons on a long journey

Gray also experimented with attaching a hemp rope to the lid of the globe. While a colleague spun the globe, he could hold the rope in the neighbouring room and still feel the strange buzzing in his hand. Gray repeated the experiment with longer and longer ropes until he finally stood in the courtyard, where he could startle passing people by giving them a shock. But there would only be a spark if the rope was suspended by silk.

That's how Gray realised that current could only move through certain materials – such as hemp, metals and water; he called these conductors. Other materials couldn't conduct electricity – such as silk and porcelain; he called these insulators. This realisation would create entirely new opportunities for the electrical experimenters who would follow.

Unfortunately, Gray didn't understand what was happening when he drew ▶

Stephen Gray (1666-1736)
Nationality: English
Discovery: Certain materials (such as copper) could conduct current away from a power source, while others (such as silk) insulate.

ALCHETRON

Three experiments boosted electrical research

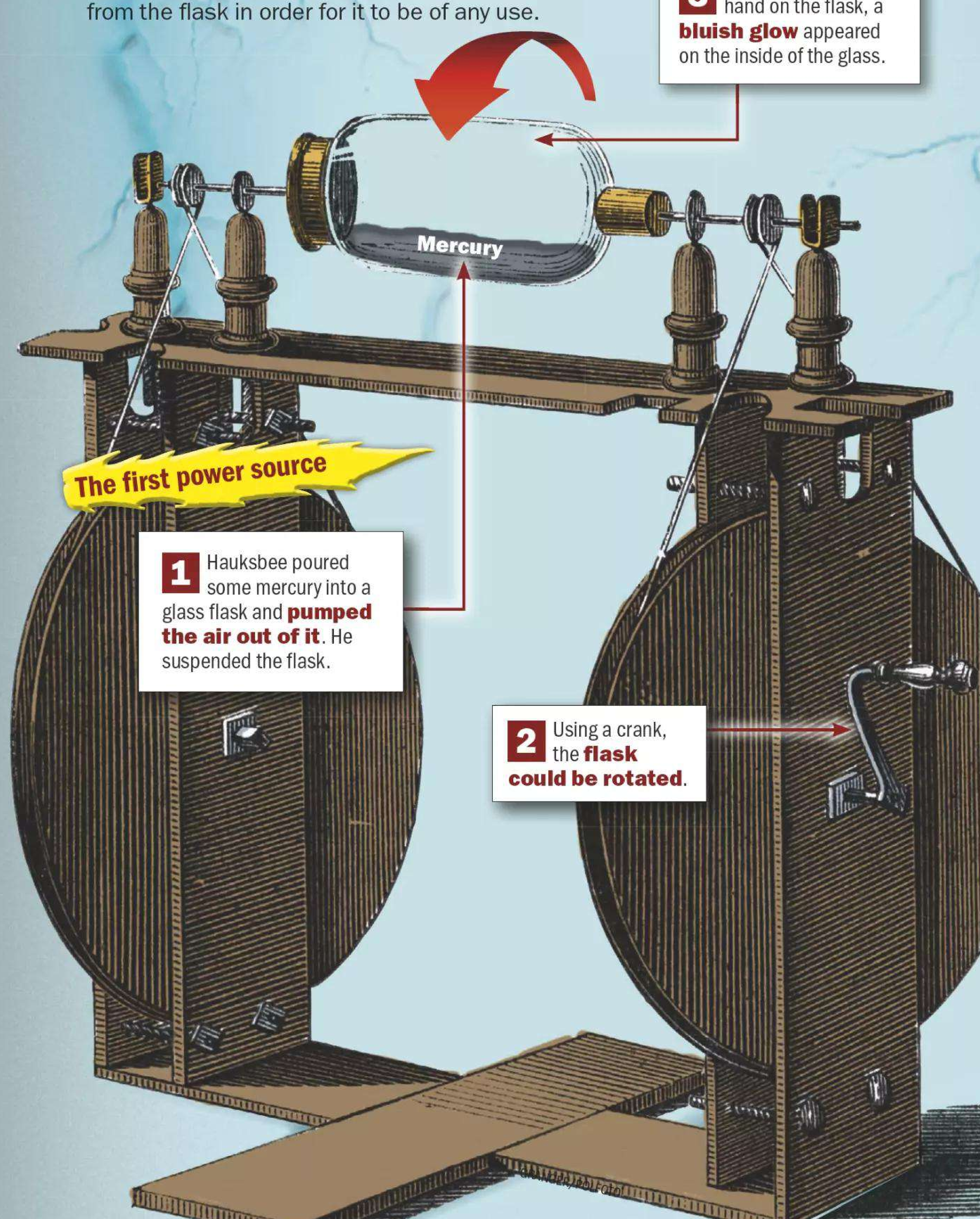
Humans had always known about lightning and static electricity in amber, but it wasn't until the 18th century that scientists began to study the phenomenon and discover the laws of nature that govern its flow.

1 Electricity can be seen

Researcher: Francis Hauksbee, 1705

Discovery: Electric light. Hauksbee discovered that by placing his hand on an airless, rotating glass flask, he could produce a flickering light. He had no idea what was going on inside the flask – the light was caused by static electricity generated when Hauksbee rubbed the glass. The current stayed inside the flask because glass insulates.

Next challenge: The electricity had to be extracted from the flask in order for it to be of any use.



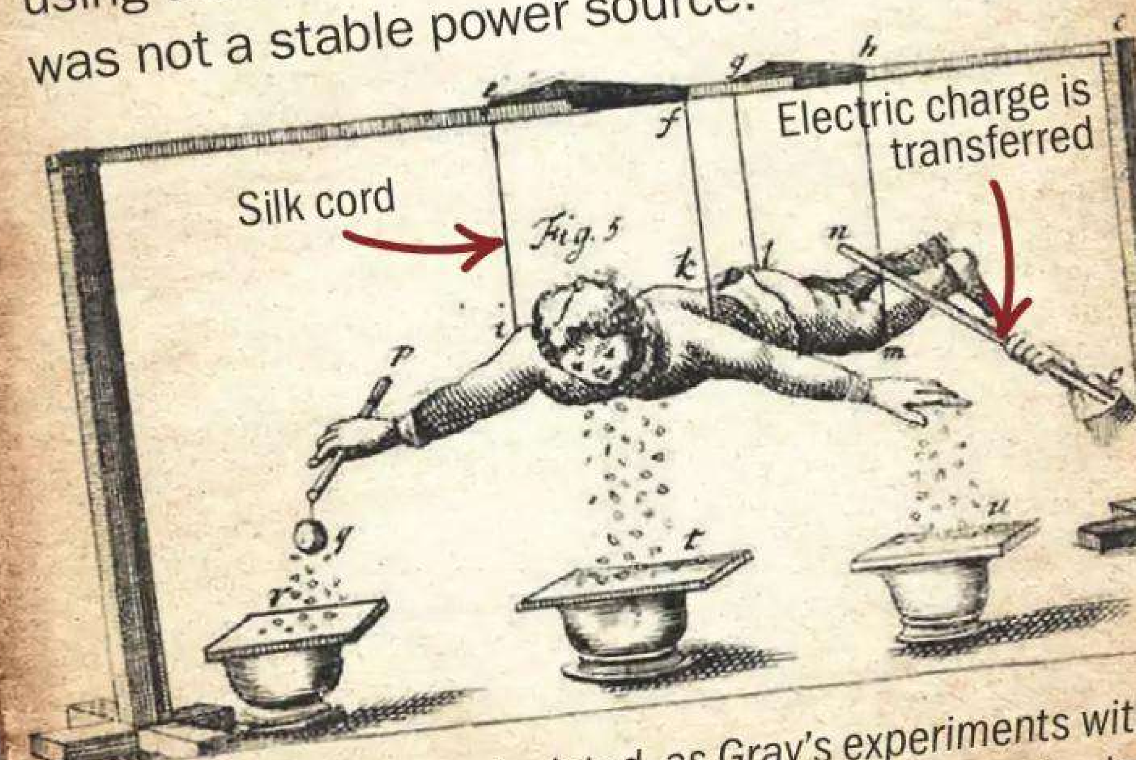
Discovery of conduction

2 Electricity can move

Researcher: Stephen Gray, 1730

Discovery: Gray discovered why electricity stayed inside the Hauksbee globe – certain materials stop electricity (such as glass and silk), others can conduct electricity away from a power source, including humans and metals.

Next challenge: Man could now send power over longer distances, but this could only be done using the hand-powered Hauksbee pump, which was not a stable power source.



Electricity can be isolated, as Gray's experiments with the boy suspended by silk showed. Using electric charge, he attracted feathers and small pieces of gold leaf.

INTERACTIVE ARCHITECTURE

Battery provided power

3 A stable source of energy

Researcher: Alessandro Volta, 1791

Discovery: By stacking alternate copper and zinc plates and wetting them with salt water, Volta created an electrical voltage. But he didn't know why. The salt water corrodes the zinc so some zinc atoms transfer two electrons to the rest of the zinc, and the positive zinc ions migrate to the copper disc. Now the zinc disc is negatively charged and the copper is positively charged – this creates an electrical voltage.

Next challenge: The power in the plates died out after a few hours. A new source had to ensure a stable power supply.

A zinc disc and a copper disc together form a cell. The more cells in the column, the higher the voltage. (Voltage is measured in volts to honour Volta.)

LUIGI CHESA

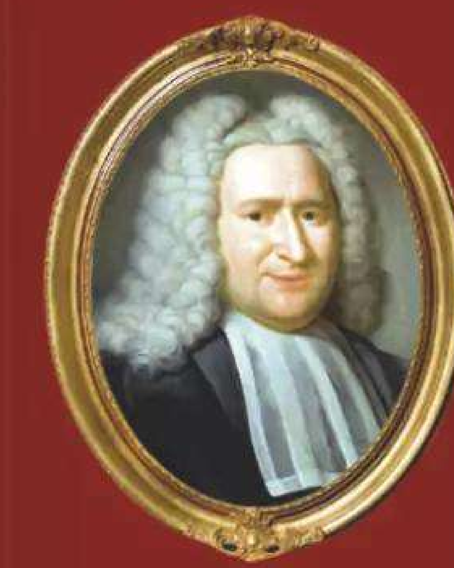
power from Hauksbee's spinning globe. It wasn't until many years later that science learned that Gray had made electrons jump from one atom to another. And by connecting the Hauksbee globe to the hemp rope (a conductor), he enabled the electrons to travel a long way from the energy source.

Power could be stored in a bottle

The new-found power that delivered sudden shocks and turned people into magnets could be used for exciting magic tricks that magicians incorporated into their performances. Floating gold leaf made grannies all over Europe gasp – and electric shocks made them squeal with fright. It wasn't until 1745 that it became clear that electricity was much more than an amusement. And this time it took more than a self-taught electricity enthusiast to realise it.

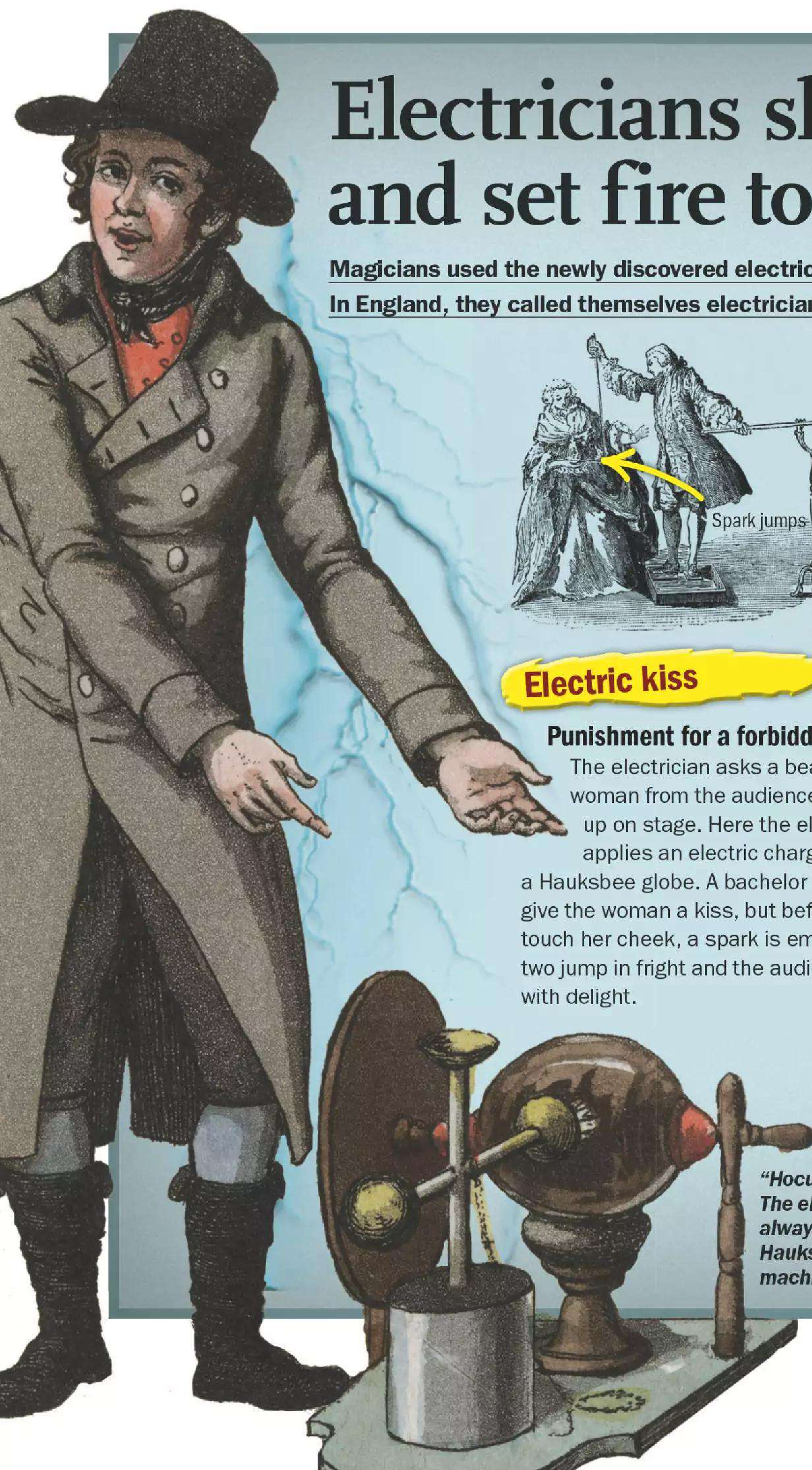
Dutch Pieter van Musschenbroek was a professor of astronomy, maths and medicine when he tackled the next challenge of electricity: could the volatile current be stored in a container – like water in a bottle – and used later? In a letter to a colleague in Paris, van Musschenbroek wrote a heartfelt warning: "I would like to tell you about a new but terrible experiment, which I advise you never to try yourself."

His experimental setup looked innocent enough: using a wire, van Musschenbroek would conduct current from a Hauksbee globe into a glass bottle of water. Stephen Gray's experiments had shown that glass insulates, while water can conduct electricity. The Dutchman



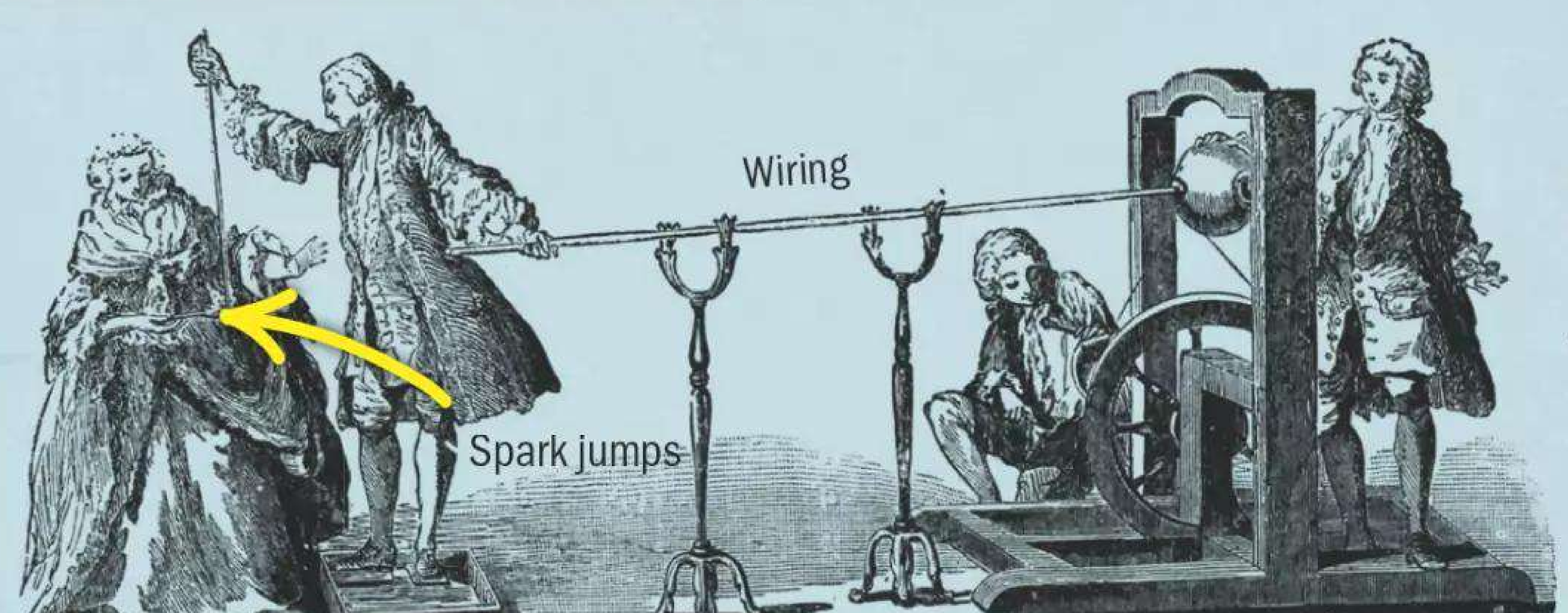
Pieter van Musschenbroek (1692-1761)
Nationality: Dutch
Discovery: He was the first person to store electricity, using a copper wire to conduct electricity into a pot of water.

HIERONYMUS VAN DER MIJ (1741)



Electricians shocked audience and set fire to cognac

Magicians used the newly discovered electricity to perform magic tricks. In England, they called themselves electricians.



Electric shocks terrified and delighted 18th-century audiences.

Electric kiss

Punishment for a forbidden kiss

The electrician asks a beautiful woman from the audience to come up on stage. Here the electrician applies an electric charge to her with a Hauksbee globe. A bachelor is about to give the woman a kiss, but before his lips touch her cheek, a spark is emitted. The two jump in fright and the audience squeals with delight.

Burning glass

Electrician has magic fingers

The electrician spins his Hauksbee globe and charges himself with electrical voltage before he moves his finger towards a glass of cognac. The audience sees with their own eyes how the electrician can ignite the liquid with his magic index finger. In reality, the alcohol vapours are ignited by a spark.

Electric halo

Power gives a dubious honour

A well-known and often powerful man from the local community is asked to sit under a copper crown that the electrician has set up on stage. A Hauksbee machine gives the crown an electric charge, causing sparks to jump from the crown to the man's head – creating the illusion of a glowing halo.

"Hocus pocus!" The electricians always brought a Hauksbee machine on stage.

M. EVANS/SCANPIX & BRIDGEMAN

held the glass bottle in one hand, while he used his other hand to spin the Hauksbee globe to create the electricity. Immediately afterwards, he touched a wire in the lid of the glass bottle – and received a shock so powerful that he was almost knocked over.

"I, who have experienced it and survived by the grace of God, [would not] do it again for all the kingdom of France," van Musschenbroek swore to his colleague in Paris.

He named the container for electricity the Leyden jar, in honour of his home town, Leiden. When the worst of the fright had passed, Pieter van Musschenbroek wrote an article about the experiment; it caused a sensation in scientific circles and was described as the most important discovery of the 18th century.

Scientists worldwide started to experiment with how much electricity they could store in a Leyden jar.

"I understand nothing"

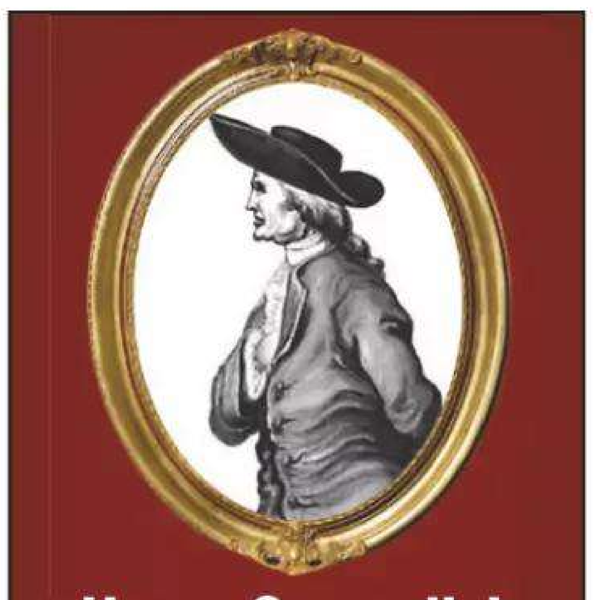
In the Netherlands, van Musschenbroek admitted that he couldn't understand how the container was filled with electric charge:

"I've found out so much about electricity that I've reached the point where I understand nothing," he candidly confessed in a letter.

On the other side of the Atlantic, scientists were also wondering about the Leyden jar: why did it give off shocks?

Benjamin Franklin, a prominent US politician, inventor and scientist, set out to find the answer. In doing so, Franklin also hoped to show the British that Americans had a role to play on the international scientific stage. Perhaps because of his business background, Franklin got the idea that electricity could be positively or negatively charged and would always try to equalise this difference – like debit and credit in a company account. As the Leyden jar was filled with negative charge, he theorised, a positive charge built up in the human body and was kept at bay by the insulating glass. When van Musschenbroek touched the wire in the bottle, the charges equalised – and he was electrocuted.

Franklin developed the theory of negative and positive charge (which would later prove to be true) without the use of measuring instruments or any knowledge of atoms.



Henry Cavendish (1731-1810)
Nationality: English
Discovery: Realised that natural and man-made electricity are the same. The difference is in their voltage and charge.

GEORGE WILSON (1851)

Loner discovered voltage

The next great electrical discovery took place in London. There lived Henry Cavendish, who had to be the strangest man in town – a rich, shy recluse. He communicated with his servants using handwritten notes. Cavendish lived in his laboratory and only emerged to attend meetings of the Royal Society, where he astonished everyone with his discoveries.

In 1773, Cavendish wanted to find out if the man-made current in the Leyden jar was the same as that of electric rays – flat tropical fish that paralyse their prey with an electric shock.

To answer the question, he charged up several Leyden jars and put them in a leather bag shaped like a ray. When Cavendish then touched his home-made 'fish', a spark shot out, electrocuting him. The shy Englishman had successfully imitated nature, but why didn't real electric rays emit sparks like the Leyden jars in the leather bag? Why did natural and man-made electricity behave differently? All winter, these questions occupied Cavendish, who had shut himself away in his laboratory.

On one of the first days of spring, it finally hit him: it was the same electricity, but it felt different because of a different amount of current and its intensity. Cavendish realised that current was the flow of charge inside the wire (what we now measure in amperes), while voltage is the pressure on the current (volts).

The electric ray gave a shock with a large charge but low voltage (30 amps and a maximum of 200 volts, according to later ▶

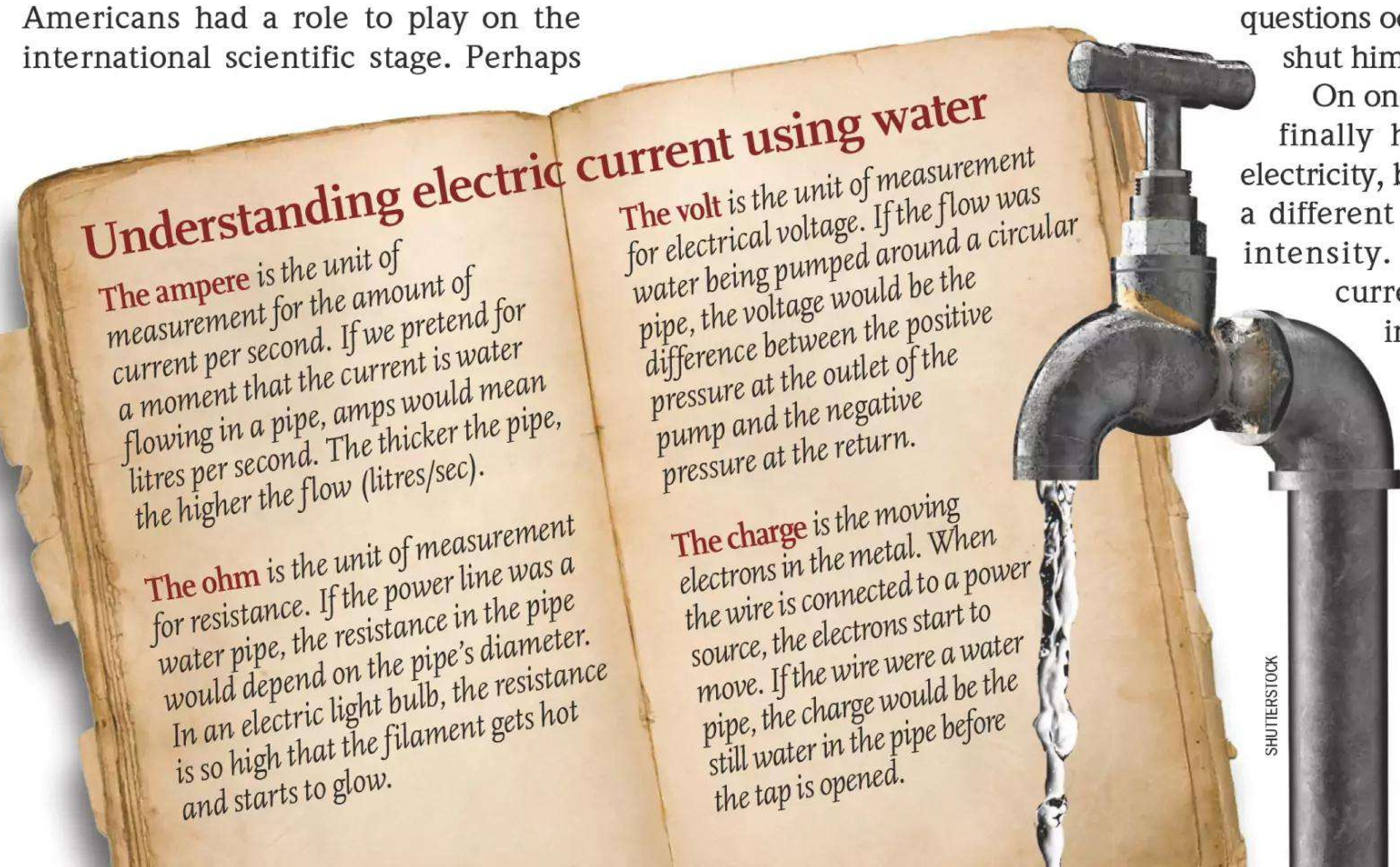
Power to wake the dead

Italian physicist Luigi Galvani successfully made a dead frog twitch using electricity – his nephew, Professor Giovanni Aldini, was convinced that electricity could even bring the dead back to life.

In 1803, he was allowed to try it on a recently hanged criminal in London. For four hours, Aldini charged the criminal's muscles so that his legs twitched and his arms waved – but the criminal did not return to life. Aldini's experiment did, however, bring a writer to life: 19-year-old Mary Shelley was inspired to write the famous science-fiction horror story of Dr Frankenstein.

Today, electricity is used in resuscitation – in the spirit of Dr Frankenstein.

GETTY IMAGES



SHUTTERSTOCK

tests). The Leyden jars in the leather bag, on the other hand, had a small charge and a high voltage (up to 2,500 volts). It was this high voltage that caused the Leyden jars to emit a spark, which was harmless due to the small charge. With this, Cavendish defined two key concepts that are still used when distinguishing between the charge of electrical current and its voltage.

Alessandro Volta (1745-1827)
Nationality: Italian
Discovery: Using salt water, copper and zinc, Volta built the first battery in history. This made it possible to perform long-term electrical experiments.

ANTHROPOSOPHIE

Power made frogs twitch

During the 18th century, scientists came a long way in their understanding of electricity, but they had yet to find a reliable power source, such as a battery.

The battery was the result of a theological dispute between two Italian scientists arguing about something completely different: did God allow electricity to flow through animals and humans? The question became topical in 1791 after Italian doctor Luigi Galvani dissected a frog in his laboratory in Bologna. While working, his wife accidentally touched the frog's spinal cord with a scalpel and suddenly the frog's legs twitched. Galvani, a devout believer, developed a theory that all living beings were filled with an electric fluid and began a long series of experiments in which he used his instruments to make the muscles of dead animals move when he touched their nerves.

This biological electricity was the very essence of life, concluded Luigi Galvani – it was proof of God's marvellous creation.

Nonsense, exclaimed Professor Alessandro Volta, who was based at the University of Pavia, just 200 kilometres away. He didn't for a moment believe that animals and humans could produce their own electricity; it had to be power from Galvani's instruments that made the cadavers twitch. Volta surmised that an electrical voltage was created because two different metals were in contact with each other during dissection.

Volta began experimenting with different metals to demonstrate that electrical pressure was created between them. And with a large audience watching in rapt attention, he made the muscles of dead animals twitch more vigorously than Galvani had managed. In the years that followed, the two Italians attempted to refute each other's claims in a vociferous scientific dispute that divided the scholars of Europe's universities. One group believed in God's creation, the other in the laws of nature.

In 1800, Volta used his knowledge of how metals interact to build a pile of zinc and copper plates. When the column of plates was wetted with salt water, a chemical reaction between the two metals began and the column produced electricity. Volta's pile was the first battery in history. Unlike the Leyden jar, which could only deliver a short burst of electricity, the column could supply a circuit with a constant electric current for

Cash flow – from research to invoice

The pioneers of electricity were gentlemen who pursued honour over money. With Michael Faraday's discovery of induction current in 1831, businessmen could see the opportunities electricity offered.

Electric train

Sped up public transport

German Werner von Siemens was not only a great inventor, but also a driven businessman. In 1866, he designed an electromagnetic generator powerful enough to run industrial machinery. But instead of remaining a scientist, the German decided to capitalise on his invention. A dozen years later, Siemens was the leading manufacturer of electric trams and traffic lights. Today, the company makes everything from coffee machines to nuclear power plants. Turnover: £60 billion per year.

Werner Siemens's electric train was unveiled in 1879. Two years later, he built Berlin's first tram line.

ALAMY/IMAGESELECT

several hours. Most scholars believed that Volta had won the argument with Galvani, but later it turned out that both Italians were right: human and animal brains give commands to the muscles via electrical impulses that run through the nervous system. Electricity can briefly 'revive' this system in dead animals and humans. So, electricity is not only found in a battery, but also in living organisms.

HC Ørsted (1777-1851)
Nationality: Danish
Discovery: The connection between electricity and magnetism. Electromagnetism is one of the natural forces. The discovery opened up a new research discipline.

CHRISTIAN ALBRECHT JENSEN (1842)

Artificial lightning bolt

Volta's column, which produced direct current, was such a ground-breaking invention that Emperor Napoleon himself wanted to see it. And it set the pace for electrical research.

One of the first scientists to use a voltaic pile in an experiment was English chemist Humphry Davy. He had been entertaining the British public for years with his sensational experiments. For example, he used two poets as guinea pigs to show the effects of laughing gas.

In 1807, he performed an even more spectacular experiment at the Royal Institution – a new organisation for scientists that had opened just eight years earlier.

The auditorium was filled to capacity and all eyes were on 31-year-old Davy. On the table in front of him, he had two thin carbon rods, each connected to a separate wire. They disappeared behind a door in the wall and into the basement, where Davy had set up the world's largest battery to date, with 800 voltaic piles lined up side by side. The metallic stench of the salt water against the zinc plates was so pungent that no one could stand to be near the 8 x 4 metre monstrosity for more than a few minutes at a time.

At Davy's command, the auditorium's many candles were blown out and in the gloom he raised the carbon rods above his head. Slowly he let them approach each other. When the gap between the tips was about 10 cm, something happened that would change history.

With a deafening crack, the first spark shot between the rods and bathed the entire auditorium in a light so intense that spectators had to cover their eyes to avoid being blinded.

For several seconds, the sputtering sound of sparks could be heard, travelling like lightning from one carbon rod to another before Davy broke the connection. For onlookers familiar only with flickering candles and gentle gas lamps, this electric light was a revelation.

Humphry Davy's invention was the basis of the arc lamp and was later used to light the streets of London, Los Angeles and Paris.

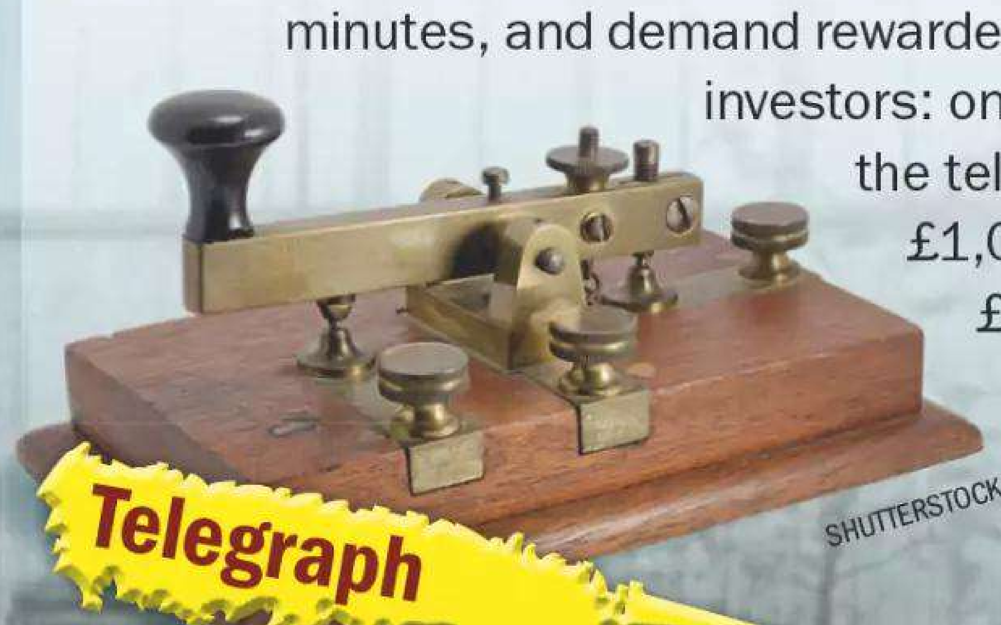
Induction could create power

The voltaic pile also contributed to a discovery that would make it possible to build power plants and electric motors.

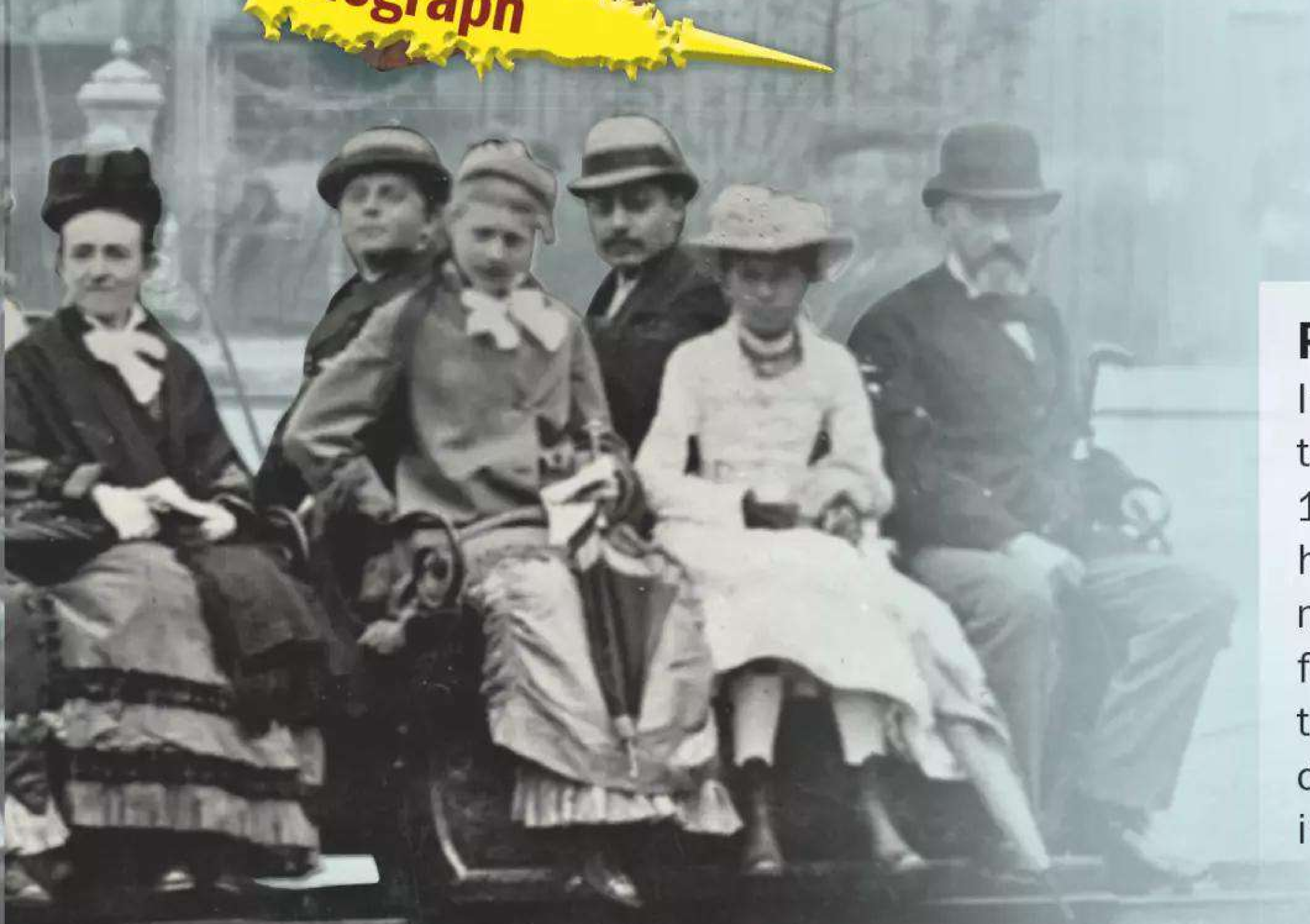
Danish physicist HC Ørsted was convinced that there had to be a connection between electricity and magnetism. For years, Ørsted travelled to Germany and France to learn from ▶

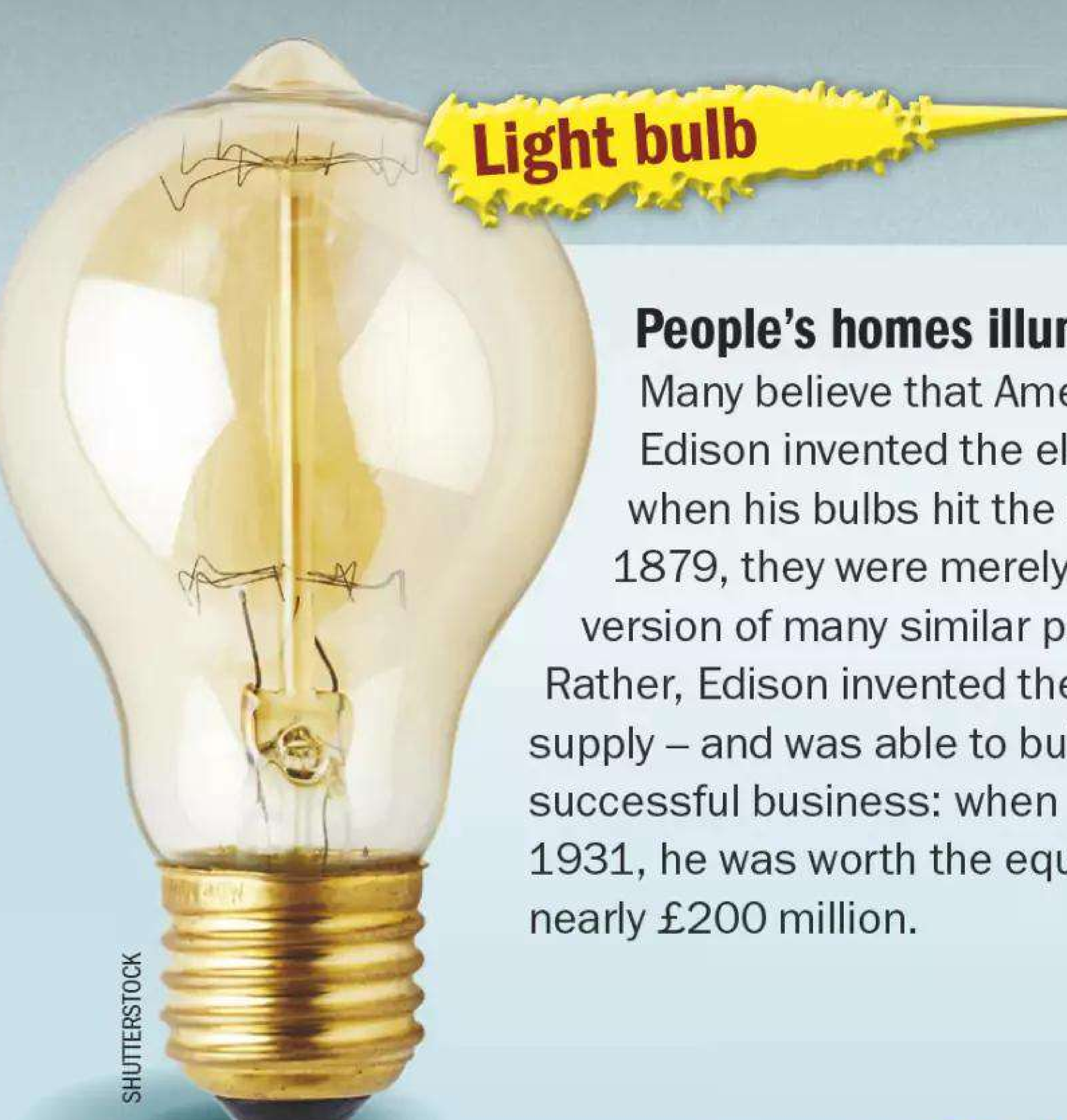
Messages sent at express speed

It would take 50 years from the invention of the telegraph in 1816 for the Atlantic Telegraph Company to lay a working cable from Ireland to Canada. At a stroke, communication between Europe and North America was shortened from weeks of sailing to minutes, and demand rewarded the company's investors: on its opening day, the telegraph made £1,000 – more than £100,000 in today's money.



SHUTTERSTOCK

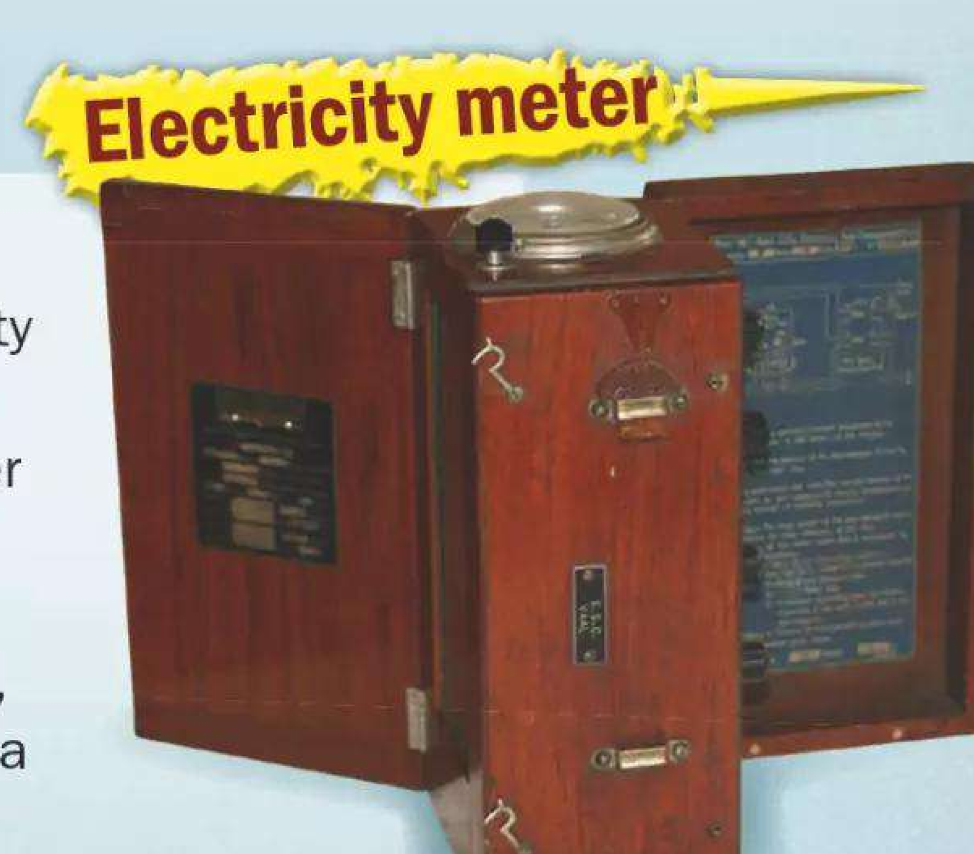




SHUTTERSTOCK

People's homes illuminated

Many believe that American Thomas Edison invented the electric light, but when his bulbs hit the market in 1879, they were merely an improved version of many similar products. Rather, Edison invented the electric power supply – and was able to build a successful business: when he died in 1931, he was worth the equivalent of nearly £200 million.



BID OR BUY

Payment for electricity

Initially, Edison charged an electricity tax for every light bulb sold. But in 1888, engineer Oliver Shallenberger had a bright idea: he developed a meter driven by electromechanical force. The greater the consumption, the faster the counter spun. Within a decade, electricity meters were installed in 120,000 American homes.

Europe's best scientists, and when he returned home to the University of Copenhagen, his head was buzzing with new ideas.

During one of his popular lectures in 1820, Ørsted applied current to a copper wire and then moved a compass needle towards the wire. At first nothing happened, but then the magnetic needle suddenly fluctuated wildly.

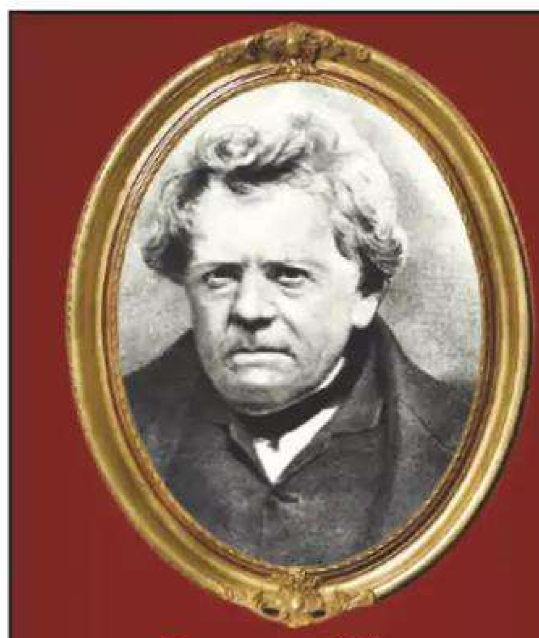
The current must have affected the magnet – even though science had so far assumed that magnetism and electricity were two different phenomena. Ørsted had discovered electromagnetism.

Laws of nature were discovered

Ørsted's discovery caused a stir in European capitals, where scientists began to investigate whether they could build upon it. In Paris, André-Marie Ampère realised that an electric coil placed around an ordinary iron rod could turn it into a magnet. This insight led to powerful electromagnets capable of lifting tonnes of metal.

In the early nineteenth century, electrical scientists discovered the phenomena of charge, voltage and voltage loss (resistance), but how these quantities interacted with each other was unknown.

The fundamental law of electricity was to be discovered by a failed university student.



Georg Ohm (1789-1854)
Nationality: German
Discovery: His mathematical skills enabled him to find the relationship between voltage, current and resistance – known as Ohm's law.

TECHNISCHE HOCHSCHULE NÜRNBERG

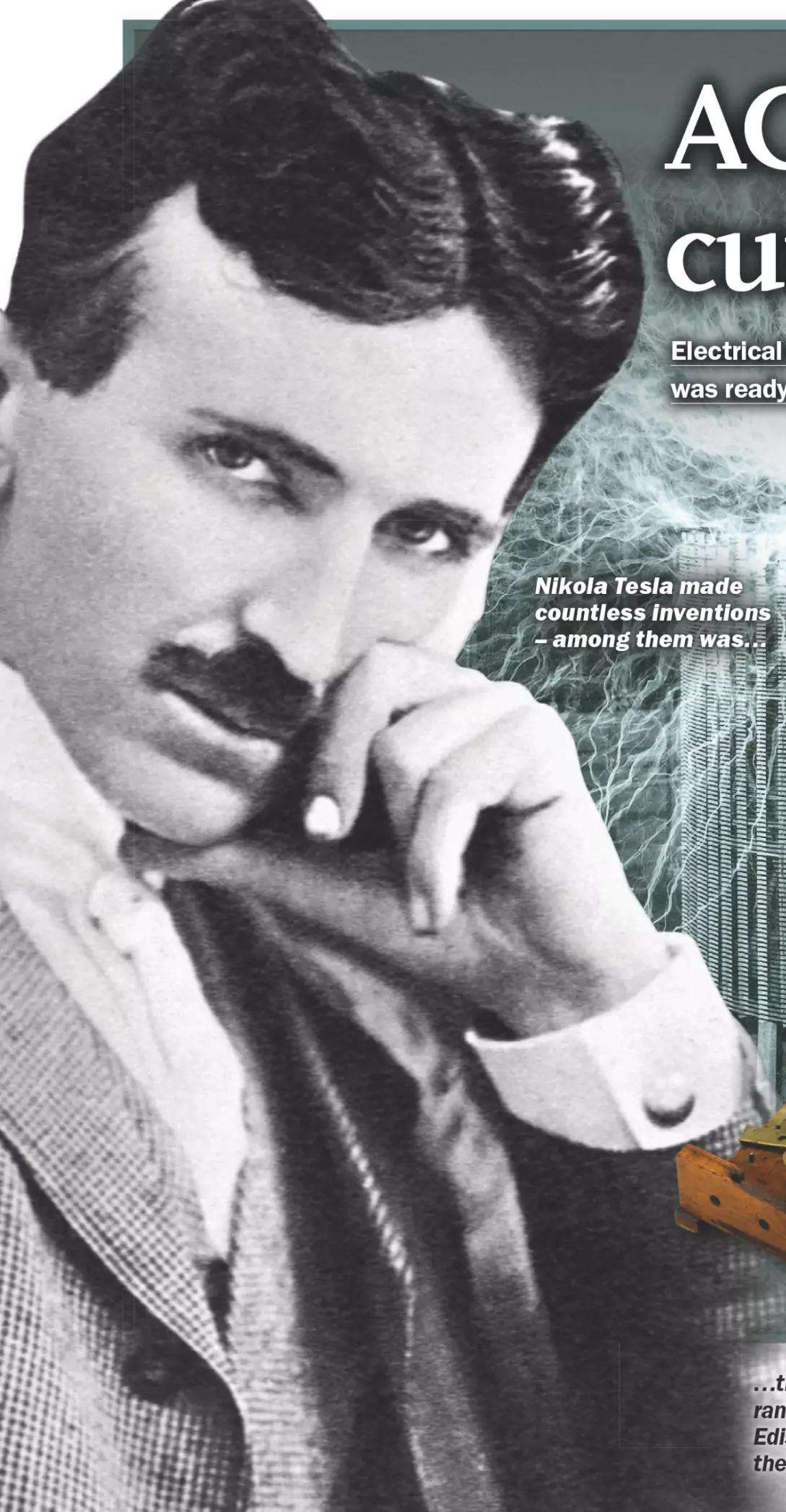
Georg Ohm, who didn't have the money to complete his physics degree, worked as a teacher at a school in Cologne.

In 1825 and 1826, he carried out countless experiments on electrical circuits that he had constructed. From the results, he discovered a very simple law: voltage = current x resistance.

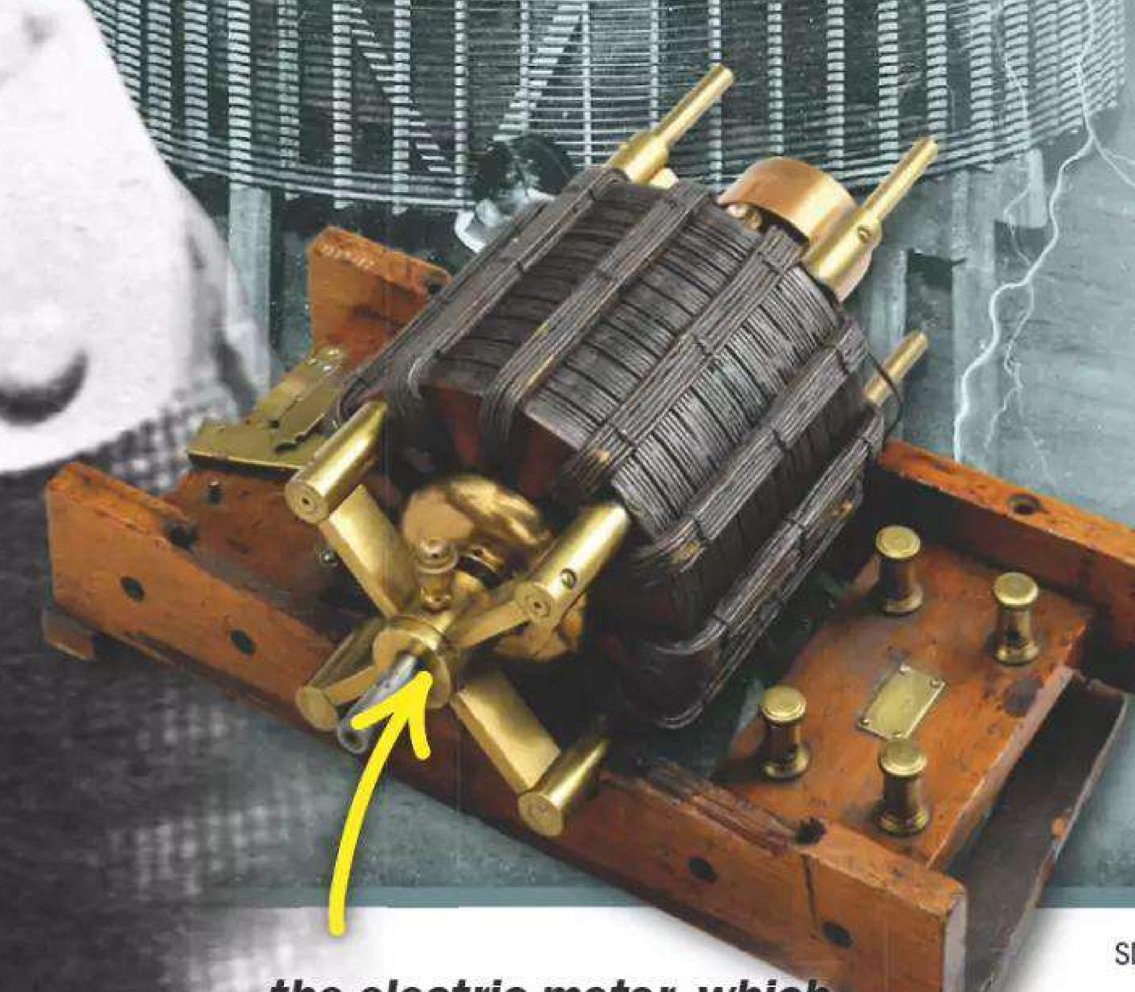
The law, later called Ohm's law, makes it easy to calculate the resistance in an electrical circuit if the voltage (volts) and current (amps) are

AC won the great current war

Electrical pioneers had one last mistake to rectify before the new power source was ready to take on the world – direct current was the wrong way to go.



Nikola Tesla made countless inventions – among them was...



...the electric motor, which ran on alternating current. Edison had effectively lost the current war.

SMITHSONIAN & GETTY IMAGES

The electric current that scientists had been working with since 1705 was **direct current** (DC, with fixed positive and negative poles). In 1882, US inventor Thomas Edison was ready to use it commercially when he opened his power plant in Manhattan.

However, direct current had one major drawback: it created so much resistance in the wiring network that the consumer could not live more than 800 metres from the plant, otherwise the voltage was lost on the way. So, Edison set about flooding the city with coal-fired power stations.

Edison had a young rival

In 1884, the inventor Nikola Tesla joined Edison's staff, and immediately tried to lecture his boss about the advantage of **alternating current** (AC, with alternating poles) – it can be sent via transformers over long distances without significant voltage loss and therefore requires fewer power plants. Edison discouraged his employee, who left the lab in anger to prove his

known. But the scientific world's praise was not forthcoming – instead, Ohm was met with contempt because he dared to put forward scientific theories as an ordinary schoolteacher. The country's minister of education even said that "a professor who preached such heresies was unworthy to teach science".

Magnetic power lines

For Ohm, the discovery of the law led to his dismissal from his school. Only when fellow scientists abroad read his 1827 publication *Die Galvanische Kette (The Galvanic Circuit)* was Ohm taken seriously and promoted to professor at the University of Munich.

While Ohm struggled to get his law recognised, others continued to explore the possibilities of electricity. With his discovery of electromagnetism, Ørsted inspired one of the most revolutionary inventions in the history of technology – again, from an unexpected direction.

Michael Faraday left school at the age of 12 to become a bookbinder, but he couldn't get enough of books. By day he bound them, in his spare time he studied them and attended countless lectures at the Royal Institution.

The bookbinder would do anything to become a scientist himself, so he bound a beautiful book of his lecture notes and sent it to the institute, where Humphry Davy was so impressed that he accepted the young man.

In 1831, Faraday was finally allowed to give his own lectures, demonstrating his experiments with magnets and electricity. When he wasn't in the lecture theatre, he worked late into the night in his laboratory.

"I am busy now with electromagnetism and I think I have got hold of a good thing," he wrote to a colleague in 1831. "But can't say: it may be a weed instead of a fish."

Faraday was trying to turn Ørsted's discovery on its head – the Dane had shown that electricity created magnetism, now Faraday wanted to prove that magnetism could create electricity.

The experiment was as simple as it was ingenious: by passing a magnet through a coil of copper wire, he created an electrical voltage. In Faraday's words, the voltage arose because the coil was affected by "magnetic lines of force".

Power for practical use

Faraday's discovery, now known as electromagnetic induction, was the final breakthrough for research.

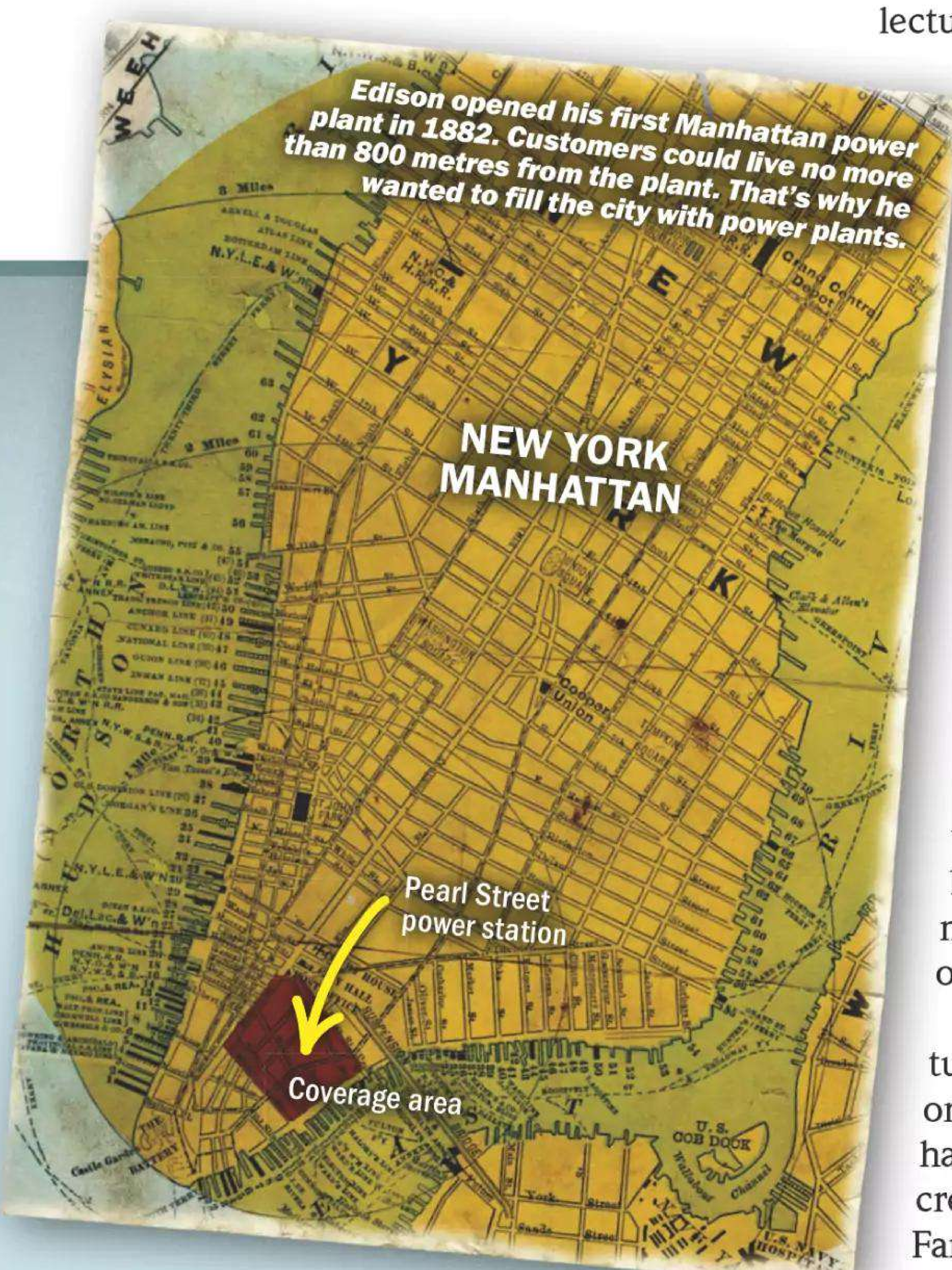
The principles of power generation were now established: steam and water power can drive a generator that produces electricity. And the same electromagnetic principles can be used in a motor driven by the current.

After Faraday, the world was changed. And just seven years after his experiment at London's Royal Institution, a crowd of onlookers in St Petersburg, Russia, got a glimpse of the future when German engineer Moritz von Jacobi piloted a boat on the Neva River.

The boat, which carried 14 passengers, sailed without the use of oars, sails or a steam engine. Instead, von Jacobi sat relaxed in the stern of the boat, keeping an eye on a mysterious device that silently drove the vessel's paddle wheels.

The secret was direct current. With the support of the tsar, von Jacobi used Faraday's discovery to construct an electromagnetic motor capable of producing 0.25 hp. At 1.5 knots, the boat sailed into history as the first usable vessel propelled by electric power.

Forty-four years later, in 1882, US inventor and businessman Thomas Edison opened a power plant in Manhattan. Now customers could have direct current delivered to their homes.



Edison opened his first Manhattan power plant in 1882. Customers could live no more than 800 metres from the plant. That's why he wanted to fill the city with power plants.

SHUTTERSTOCK

claim. The following years saw a **current war** in the US as Edison and Tesla tried to convince customers of the benefits of their type of electricity.

War was settled

The first breakthrough for alternating current came when Tesla invented an electric motor that ran on alternating current in 1887. This made his power source interesting for industry.

The final defeat of direct current was at the 1893 Chicago World's Fair, where Tesla and businessman George Westinghouse provided power. Their price was a million dollars lower than Edison's, and the 100,000 light bulbs they provided turned night into day.

Michael Faraday (1791-1867)

Nationality: English
Discovery: Induction – a magnet generates current when moved through a copper coil. Industrial production of electricity was now possible.

THOMAS PHILIPS (1842)

Baghdad Battery: the jar contained a copper cylinder and a piece of iron.

TOPFOTO/POLFOTO

Is the history of electricity wrong?

In 1938, archaeologists found a remarkable jar near Baghdad, Iraq. The 13-cm-high vessel contained a copper cylinder and an iron rod. As it also contained traces of acidic lemon juice, it could be an ancient battery. Reconstructions have shown that it could produce 0.8-2 volts (like a standard AA battery).

If the so-called Baghdad Battery is indeed a battery, electrical history will have to be rewritten. The jar is dated to 230 BC – 2,000 years before the voltaic pile. But what the battery was used for is unknown, and it may just have been a container for lemon juice.

Galápagos hid clue to mystery of life

Tame birds in trees and reptiles everywhere on the ground. Encountering the unspoiled Galápagos Islands set Englishman Charles Darwin on the trail of the origin of species. His theory of evolution challenged millennia of superstition and eventually made even devout Christians doubt the words of the Bible.

BY JØRN MADSEN

Englishman Charles Darwin had never seen such tame birds before. Finches perched barely a metre away from him and, to his great surprise, the seabirds that sat near him in trees barely noticed the curious naturalist. He was even able to push a bird of prey off a branch with his loaded rifle.

Chatham Island in the Galápagos archipelago west of South America was the closest 26-year-old Charles Darwin had come to Heaven, and the inhabitants, all animals, seemed to think so, too. In his letters, he enthused that the islands were "a paradise for the reptile order", with giant tortoises and lizards everywhere.

Numerous popular portrayals of Darwin's life describe how, upon encountering the island wildlife in 1835, he suddenly realised that the world's species descended from a common ancestor. Apparently, he realised that over millions of years, that common ancestor had gradually changed into the myriad species that scientists know today. This happened through natural selection, where the animals that were best able to adapt to their living conditions survived. That's why some finches had strong beaks for crushing seeds, while others had delicate beaks for catching insects, and why the turtles on different islands had very different shells. But this sudden revelation is pure fiction. Darwin did not formulate his ground-breaking theory of evolution until long after his visit to the islands. In fact, his diaries and travelogues show that he was blind to even the most obvious clues of evolution.

Tortoises adapted to the islands

Barely four years earlier, in 1831, Charles Darwin had left Plymouth in southern England aboard the British brig-sloop HMS *Beagle,* whose captain, Robert FitzRoy, had been commissioned to map the coasts of South America. Good connections in academia had secured Darwin the position of the ship's natural historian, and he had also been

Darwin cracked riddle of life
At the age of 26, Charles Darwin set off on a five-year expedition that would define his life.

GETTY IMAGES

Finches tricked Darwin
Darwin collected a number of specimens of what he thought were different bird species. On returning home, it turned out that they were all finches that just differed from island to island.

Isolated paradise for animals
Several of the Galápagos Islands were almost untouched by humans. This had created diverse wildlife.

chosen as an appropriate travelling companion for the captain.

However, Darwin soon discovered that he was not at all suited to the sea.

"I hate every wave of the ocean," he wrote to a friend.

He also didn't enjoy the captain's company, so whenever the opportunity arose, he went ashore on lengthy trips to collect animals, plants, fossils and minerals.

On the morning of 17th September 1835, HMS *Beagle* docked at Chatham Island in the Galápagos archipelago and, as usual, Darwin jumped ashore. Over the next few weeks, he visited four of the archipelago's 13 major islands, marvelling at the unique flora and fauna.

Most impressive were the marine iguanas that swam down to feed on the algae covering the rocks. He'd never seen an iguana do anything like that before.

The Galápagos Islands were formed by volcanic activity and one of Darwin's greatest wishes was to see an active volcano. Unfortunately, all of Chatham's craters were long extinct, but he noted that the island was almost completely black with solidified lava that resembled frozen waves. He agreed with Captain FitzRoy that the scene was reminiscent of the landscape around the great furnaces of the Wolverhampton ironworks back in England.

The next stop on the journey was Charles Island. There lived a small colony of convicts, led by vice-governor Nicholas Lawson. Lawson said he could tell ▶

Darwin trumped God

Before Darwin formulated the theory of evolution, science had to look to the Bible to explain the origin of animals and plants.

BEFORE DARWIN

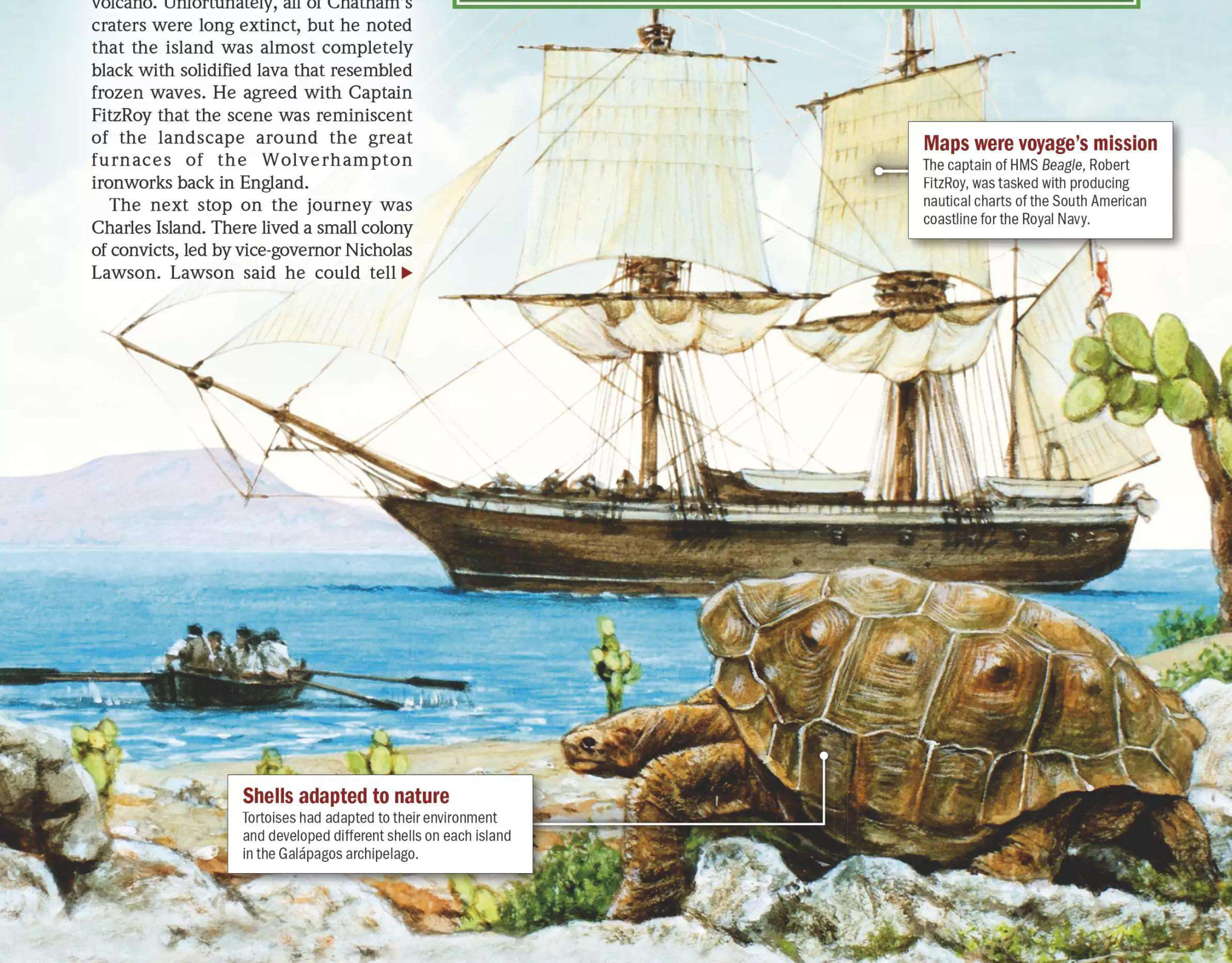
Most natural historians believed that all species were **immutable** and created by a god who had put them in their proper place on the planet. Therefore, many also believed that the Earth was only a few thousand years old.

However, a few naturalists believed that species were mutable, but that they evolved according to a fixed – perhaps divinely ordained – plan or as a result of some kind of intangible inner necessity. Even evolutionists had to resort to metaphysical explanations to make sense of it all.

AFTER DARWIN

All of the planet's countless life forms are connected in a family tree with ancient roots, and the Earth is many millions of years old, perhaps hundreds of millions of years. Most importantly, **natural selection** explains the many evolutionary changes and speciation.

Darwin's theory provided natural historians of the time with a satisfactory explanation for the many small and often fluid transitions between species. Evolution had been rationalised and taken away from the divine, back down to Earth, where it could be studied scientifically.

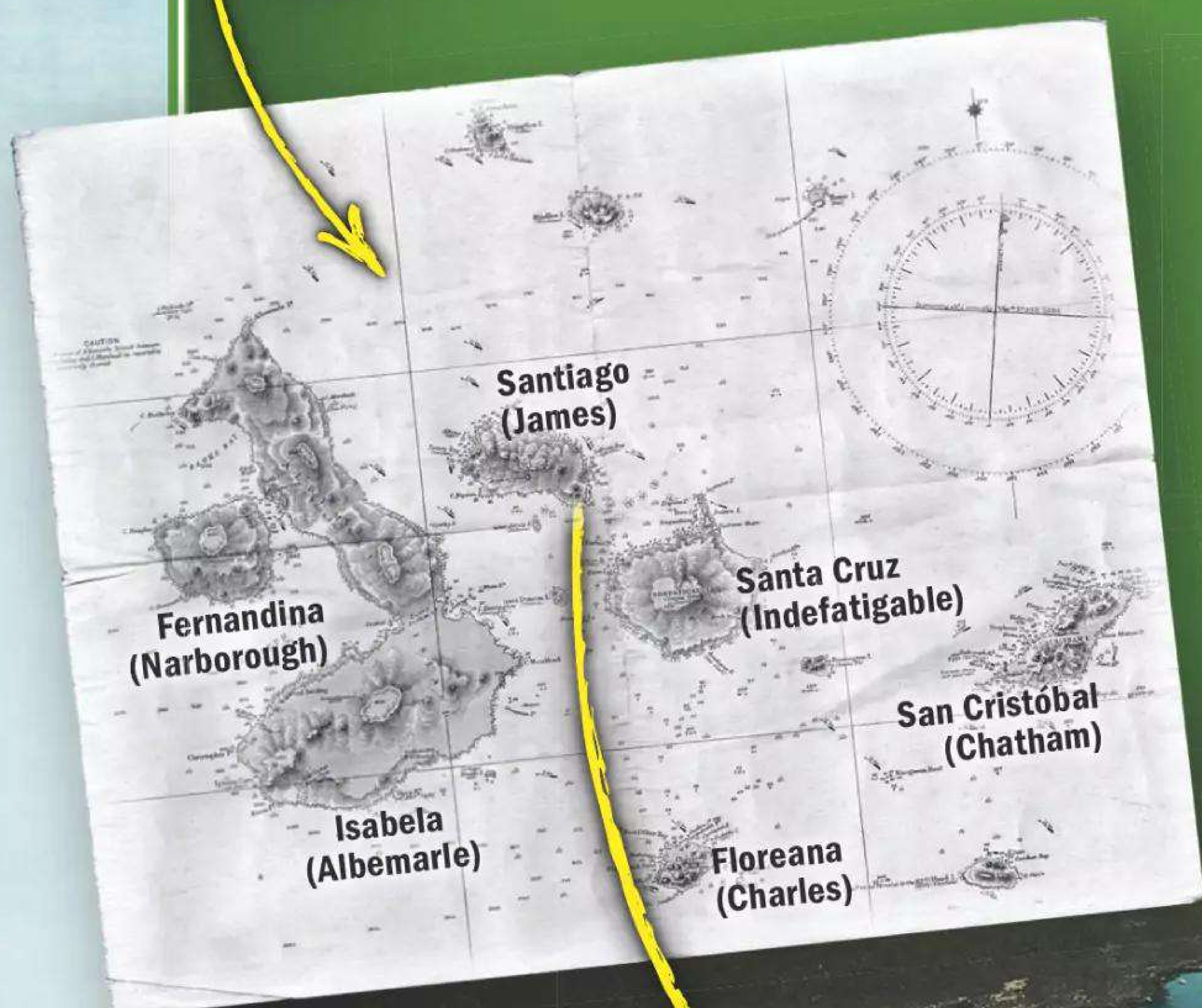


Maps were voyage's mission
The captain of HMS *Beagle*, Robert FitzRoy, was tasked with producing nautical charts of the South American coastline for the Royal Navy.

Shells adapted to nature
Tortoises had adapted to their environment and developed different shells on each island in the Galápagos archipelago.

Islands created by volcanoes

The Galápagos Islands are 1,000 kilometres from the nearest mainland. This isolated location has provided unique conditions for wildlife to develop undisturbed.



In **1535** the islands were discovered by accident by Spanish explorers. They found no trace of humans.

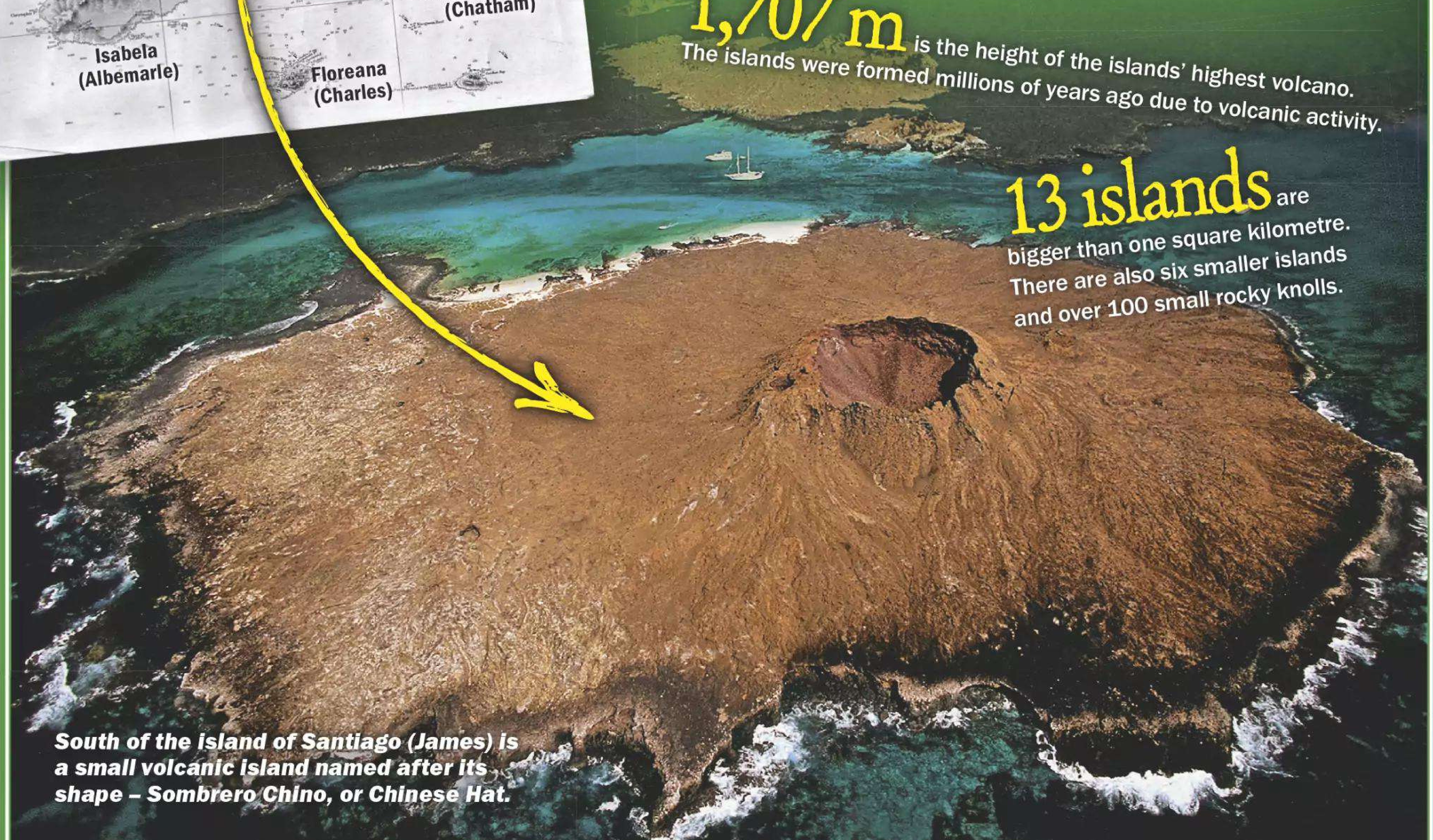
95% of the Galápagos Islands' reptiles are only found there. The same goes for 49% of the archipelago's birds.

From **1832** the islands were part of Ecuador.

Only **5** of the islands are inhabited by humans. The rest of the archipelago is a nature reserve.

1,707 m is the height of the islands' highest volcano. The islands were formed millions of years ago due to volcanic activity.

13 islands are bigger than one square kilometre. There are also six smaller islands and over 100 small rocky knolls.



South of the island of Santiago (James) is a small volcanic island named after its shape – Sombrero Chino, or Chinese Hat.

GETTY IMAGES & BRITISH ADMIRALTY

which island he was on just by looking at the giant tortoises' shells, which varied from island to island. On some islands, the shell rim at the head end curved upwards, enabling the animals to feed on taller bushes and trees. On others, the ridge was flat and the animals fed on low grasses and did not have to stretch their heads far for food.

The tortoises had other differences, too, but even though Darwin was able to study first-hand plenty of tortoise shells that Lawson was using as flower pots, he didn't yet realise the significance of the vice-governor's information. Before leaving the Galápagos Islands, the *Beagle* stopped at Albemarle, where Darwin studied the island's land iguanas, and James Island, where he rode on the back of a giant tortoise.

When Darwin left the islands after five weeks under the scorching equatorial sun, he was not yet an evolutionary theorist, but he had seen much of the world and gained experiences that made sense when he started putting two and two together later in life. In his travelogue, published in 1845, nine years after returning home, Darwin said that at first he hadn't understood all the clues of evolution – partly because he couldn't imagine that islands within sight of each other could harbour such different manifestations of the same animal species.

He later regretted that he had not made thorough tortoise collections. Instead, all the tortoise shells were thrown overboard when it was their

Darwin's theories caused wild debate when they were published in 1859.
BRIDGEMAN

owners' turn to end up in HMS *Beagle's* cooking pots.

However, Darwin had noticed that one order of animals was represented by different species on the different islands – the passerines. He took home a neat collection of specimens with carefully crafted labels that showed the great variation among the subgroup of mockingbirds. Some other passerines he thought were a mixture of finches, thrushes and warblers, a classification he based mainly on beak shape. Back in London, Darwin gave the collection to ornithologist John Gould, who told the puzzled Darwin that the birds were all from the same subgroup – the finch family – but looked different from each other. But Darwin's mistake can be excused, as the 14 species that scientists today classify his finches into are very different, and are perhaps the most difficult group of birds for ornithologists to identify.

Finches were best example

Back home, Darwin gathered his notes and memories and tried to draw a conclusion. He decided that the diversity of life was so great that it could only be explained by the constant creation of new species that adapt to their habitats – such as the tortoises.

The modern theory of evolution slowly took shape, and he realised that the finches that had confused him were one of the best examples of evolution at work. However, his ideas were so controversial within the Christian community of the period that he waited several years before publishing them. It wasn't until Thursday 24th November 1859 that he gathered enough courage to publish his work, *On the Origin of Species.* The print run of 1,250 copies was snapped up on the day of publication, and in the aftermath, a heated debate for and against the theory ensued, even though few readers understood what he meant by "natural selection".

More than 20 years after his voyage, people could read Darwin's revolutionary words that claimed his studies of birds "seemed to throw some light on the origin of species – that mystery of mysteries".

Scientists are in no doubt that this realisation was largely due to his experiences in the Galápagos Islands. And since Darwin wrote those words, numerous studies and expeditions have confirmed his theory.

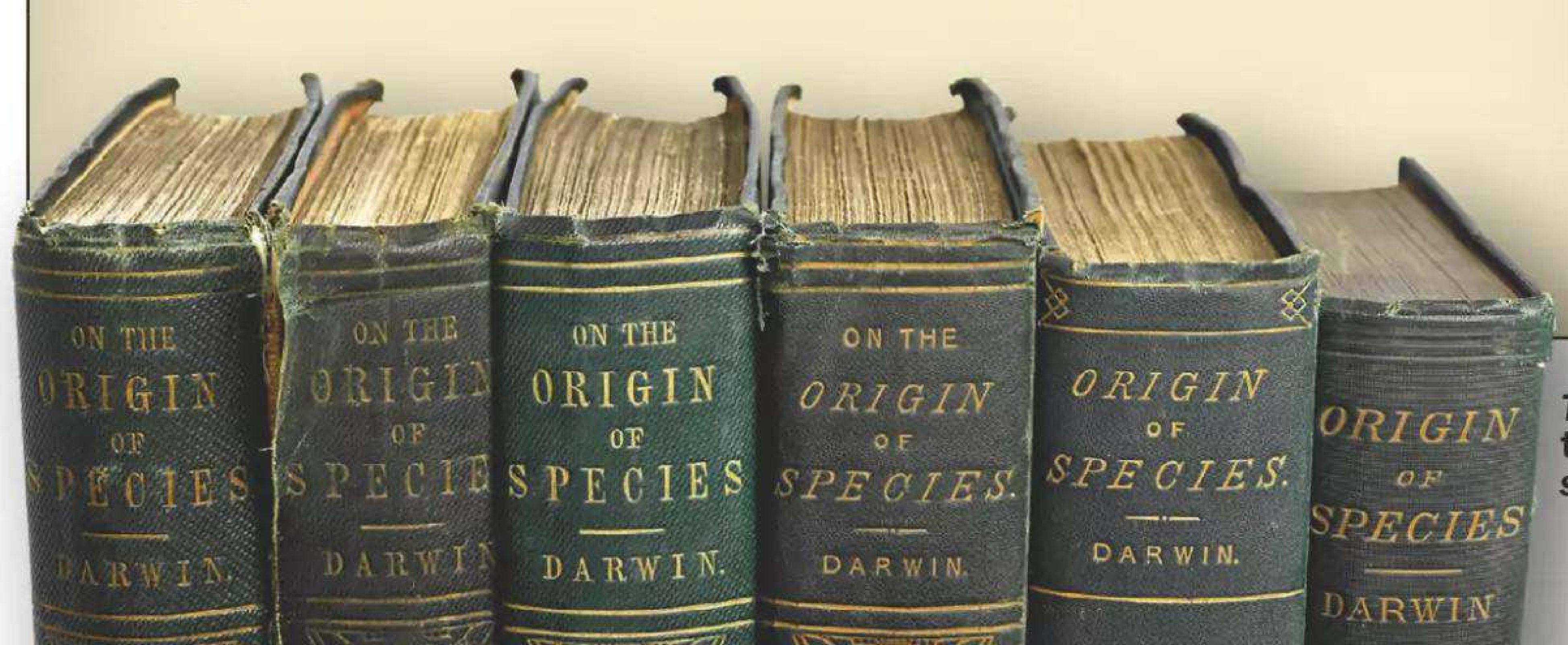
WELLCOME IMAGES

Darwin's theory consists of two parts

Charles Darwin's ideas on evolution were so ground-breaking that they came to be known as Darwinism. His theory contains two elements.

All species originate from a common starting point: The first part of the theory describes evolution, or slow change. Darwin claimed that all species originated by gradually changing from a common ancestor.

The best adapted offspring survive: The next step is that the gradual changes occur through what Darwin calls natural selection; the best adapted individuals in each generation produce more offspring than those animals that are less adapted to the living conditions. This law – also known as survival of the fittest – drives evolution.



The first edition of **On the Origin of Species** *sold out in one day.*

NEW INVENTIONS SHOOK THE WORLD

Since ancient times, inventions have been met with widespread scepticism. Anything new would ruin people's memory, destroy the nuclear family and corrupt women, people have claimed, going back as far as the days of Socrates in ancient Greece. But innovations have subsequently flourished all over the world.

BY EMRAH SÜTCÜ

Fear of bikes

"CYCLING makes women ugly!"

Memory loss, depression and bicycle face – these were just some of the terrible harms that cycling would cause women, doctors warned.

THE 1890s were the decade of the bicycle in the Western world – women, in particular, embraced the new mode of transport and moved freely around the urban landscape. While women rejoiced, many men of the time were deeply concerned about the new two-wheeled female liberation. In response, male doctors began to warn that the speed and vibrations of bicycles could do irreparable damage to the weaker sex.

According to doctors, female cyclists were at risk of memory loss, depression and having their uterus shaken loose, among other things. However, the most feared consequence was so-called "bicycle face".

"Over-exertion, the upright position on the wheel, and the unconscious effort to maintain one's balance tend to produce a wearied and exhausted bicycle face," wrote the American weekly magazine *The Literary Digest* in 1895, referring to "English medical papers". According to these reports, women cyclists would develop a pale complexion, shadows under the eyes and a chronically worn-out expression. One newspaper claimed that bicycle face was God's punishment for women who cycled on Sundays instead of going to church.

"Christianity is largely dependent upon a proper observance of the Sabbath. The bicyclists are doing much to destroy the Sabbath, and at the same time are injuring their own bodies and souls. The 'bicycle face' indicating extreme weariness and exhaustion, due to the severe strain of violent exercise on seven days of the week, will be followed … with moral weariness and exhaustion," the newspaper predicted.

Towards the end of the 1890s, however, fears of the disorder were finally put to rest when several doctors realised that a strained facial expression was normal during strenuous physical activity.

"The painfully anxious facial expression is seen only among beginners, and is due to the uncertainty of amateurs. As soon as a rider becomes proficient, can gauge her muscular strength, and acquires perfect confidence in her ability to balance herself and in her power of locomotion, this look passes away," a doctor concluded in 1897.

From balance bike to lightning-fast iron horse

1817 German Karl von Drais invented a primitive bicycle on which the rider pushed his way along with his feet. The swiftwalker was popular in Europe, but it was uncomfortable and its popularity declined in the 1830s.

1839 The steam locomotive's power transmission from valve to wheel gave Scotsman Kirkpatrick MacMillan the idea for the first bicycle with pedals. His bike did not have a chain, but pulled the rear wheel using connecting rods. It was not a commercial success, however.

1861 Blacksmith Pierre Michaux built the velocipede – a bicycle with pedals on the front wheel and brake pads on the rear wheel. It was popular and factories opened in both France and Britain to mass-produce velocipedes.

1870 The penny farthing was invented when bike makers enlarged the front wheels of the velocipede to make it faster. The first wheels were 120 cm high, but over the years they became larger and larger to increase speed. The first bike races were run with penny farthings.

1885 Englishman Harry John Lawson gave the bicycle a chain drive. His model was clumsy and impractical, but was further developed into the safety bicycle, which was fast and easy to ride. This type is similar to the modern bicycle.

1890s A series of improvements – including air-filled rubber tyres, reliable brakes and gears – made the bicycle a comfortable and reliable means of transport that became commonplace.

VELOCIPEDE MICHAUX, PHOTO BY LESSEPS, FIESTOFORO & IMAGESELECT

The bicycle became a symbol of women's liberation that many men opposed.

GETTY IMAGES

Small device sparked fears for future

"TELEPHONE fragments society!"

Citizens losing interest in their community, families only getting together for the holidays, and people prying into each other's private lives. Trust in the telephone was at an all-time low in the 19th century.

IN 1876 Alexander Graham Bell unveiled a new device: the telephone. Although the invention was plagued by a crackling noise, one eyewitness excitedly exclaimed: "It was like a voice from another world."

Many enthusiastically embraced the new, ground-breaking technology that rapidly spread across the US at the end of the 19th century. Others were less impressed. The most pessimistic feared that Bell's invention would disintegrate society as telephone conversations replaced face-to-face contact. This would ultimately mean that citizens would lose interest in their community. For example, in 1893, author Julian Hawthorne predicted that the telephone would turn the US into a highly fragmented society in which citizens would only surround themselves with people of the same "sentiment and quality". They would live in small, isolated colonies, communicating by phone, and only meeting with others for special occasions. Some critics feared the opposite: that the phone would invade privacy and allow people to pry into each other's affairs around the clock.

"Thanks to the telephone, motor-car and such-like inventions, our neighbours have it in their power to turn our leisure into a series of interruptions," wrote a concerned American professor, while some sceptics feared that the constant stream of speech would prevent people from thinking.

"The use of the telephone gives little room for reflection," a British newspaper lectured in 1899, and continued: "It engenders a feverishness which does not make for domestic happiness and comfort."

In 1892, Alexander Graham Bell made the first call from New York to Chicago.

GETTY IMAGES

Who invented the phone?

The question of who invented the telephone is controversial. To this day, historians cannot agree on who the real inventor was. Three men fight for the honour:

Alexander Graham Bell (1847-1922)

Bell was the first to receive a patent for the telephone in 1876. His application was filed on the same day as Elisha Gray's, but Bell was granted the patent because his lawyer insisted on paying the application fee immediately. This meant Bell's application was registered first.

Elisha Gray (1835-1901)

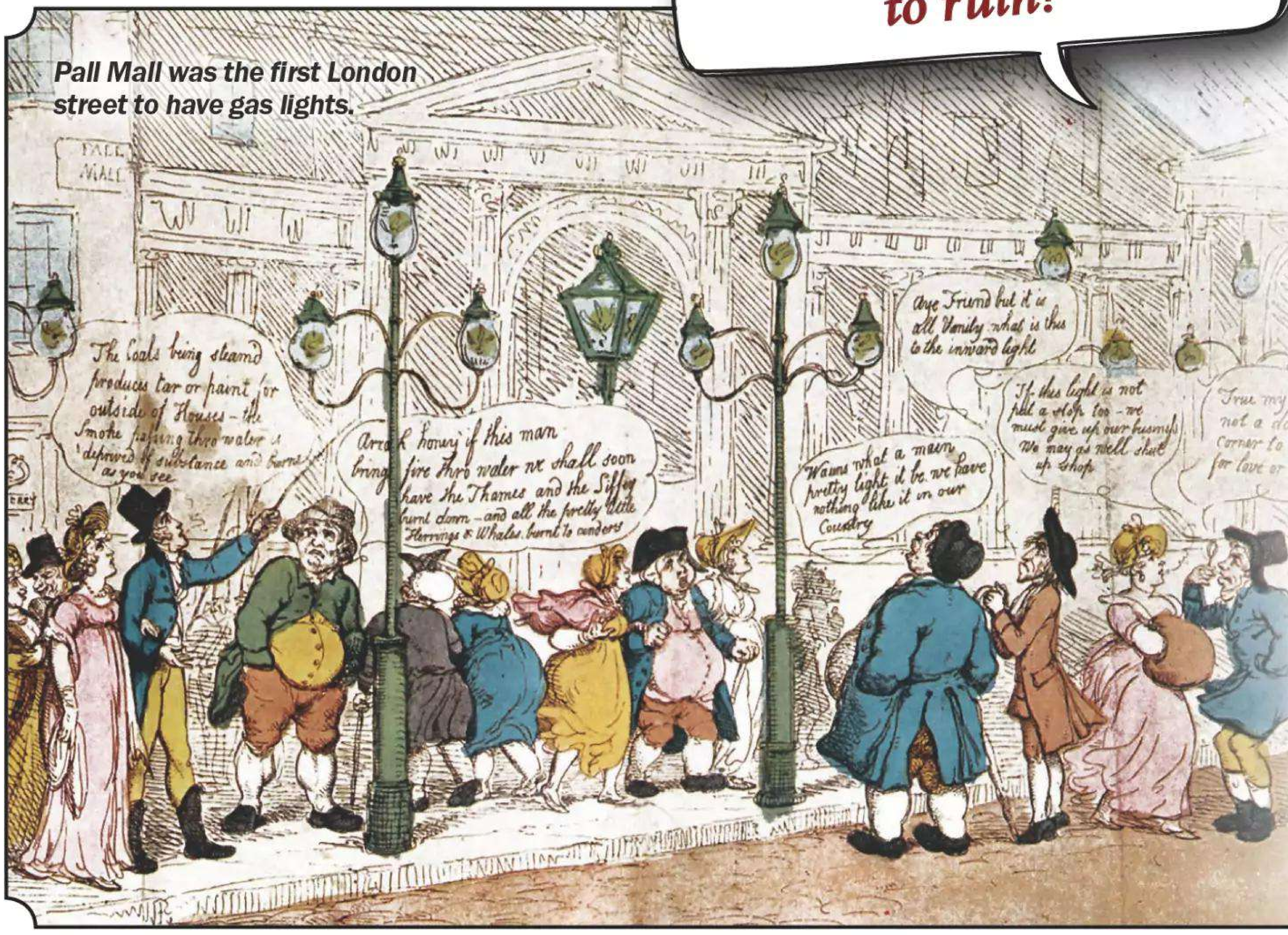
Electrical engineer Elisha Gray was beaten to the finish line by Bell, even though he had been working on his own telephone for years. Gray filed a series of lawsuits against Bell to prove he had invented the telephone first, but his complaints were in vain.

Antonio Meucci (1808-1889)

In 2002, the US House of Representatives recognised Italian Antonio Meucci as the inventor of the telephone. As early as 1860, he developed the *telettrofono*, which he patented in 1871. Unfortunately, Meucci did not realise that the patent had to be renewed after five years and lost the rights to his great invention.

LIBRARY OF CONGRESS & ASHLEY EZELL

“GAS LIGHTS lead to ruin!”



Pall Mall was the first London street to have gas lights.

GEORGE M. WOODWARD

Gas was a threat to tradition

IN 1812, London and later other European cities got gas lights in their streets. The new lamps made cities brighter and safer to travel in at night.

But in Rome, the Catholic Church opposed gas lighting. Pope Gregory XVI abhorred technology and also banned railways and steamships as they were the work of the Devil.

Pope Gregory is reported to have said: “My pious subjects are in the habit of vowing candles to be burned before the shrines of saints, the glimmering candles would soon be rendered ridiculed by the contrast of the glaring gas-lights, and thus a custom so essential to everlasting salvation would fall into general contempt, if not total disuse.”

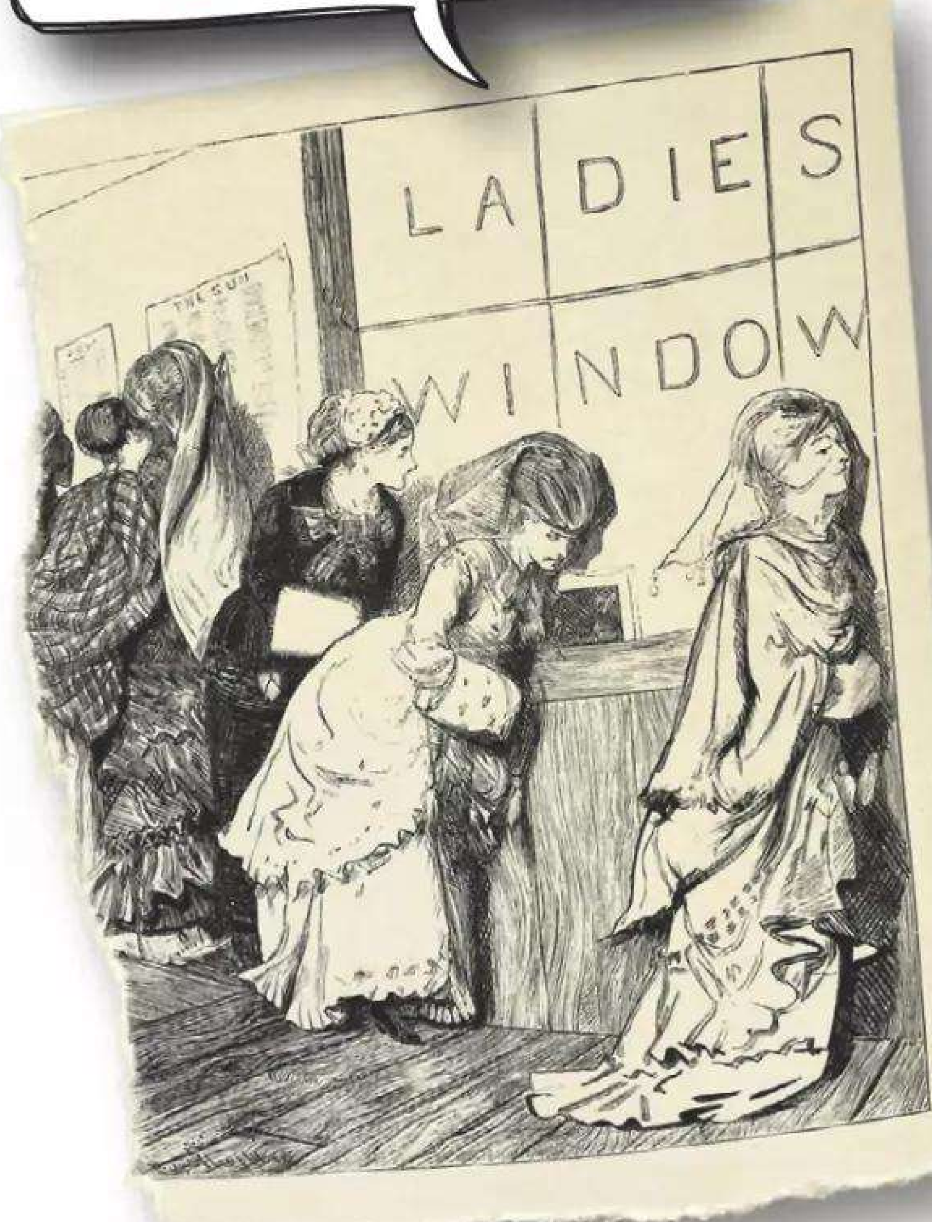
“GRAMMAR is the Devil’s work!”

Language rules met with Church protests

IN THE MIDDLE AGES, grammar was a popular discipline among scholars who sought to develop Latin as a language. But critics saw grammar as a rebellion against God – the strict rules of language were interpreted as a sign of moral decay and an attack on God’s omnipotence. Among the most ardent critics was the Italian Cardinal Peter Damian (1007-1072). He insisted that grammar perverted divine truth because it focused on form and structure rather than content and truth.

“While [the Devil] initiates a new art of disobedience, he introduces into the world an unheard of rule of declension,” Damian said.

“POST turns women into prostitutes!”



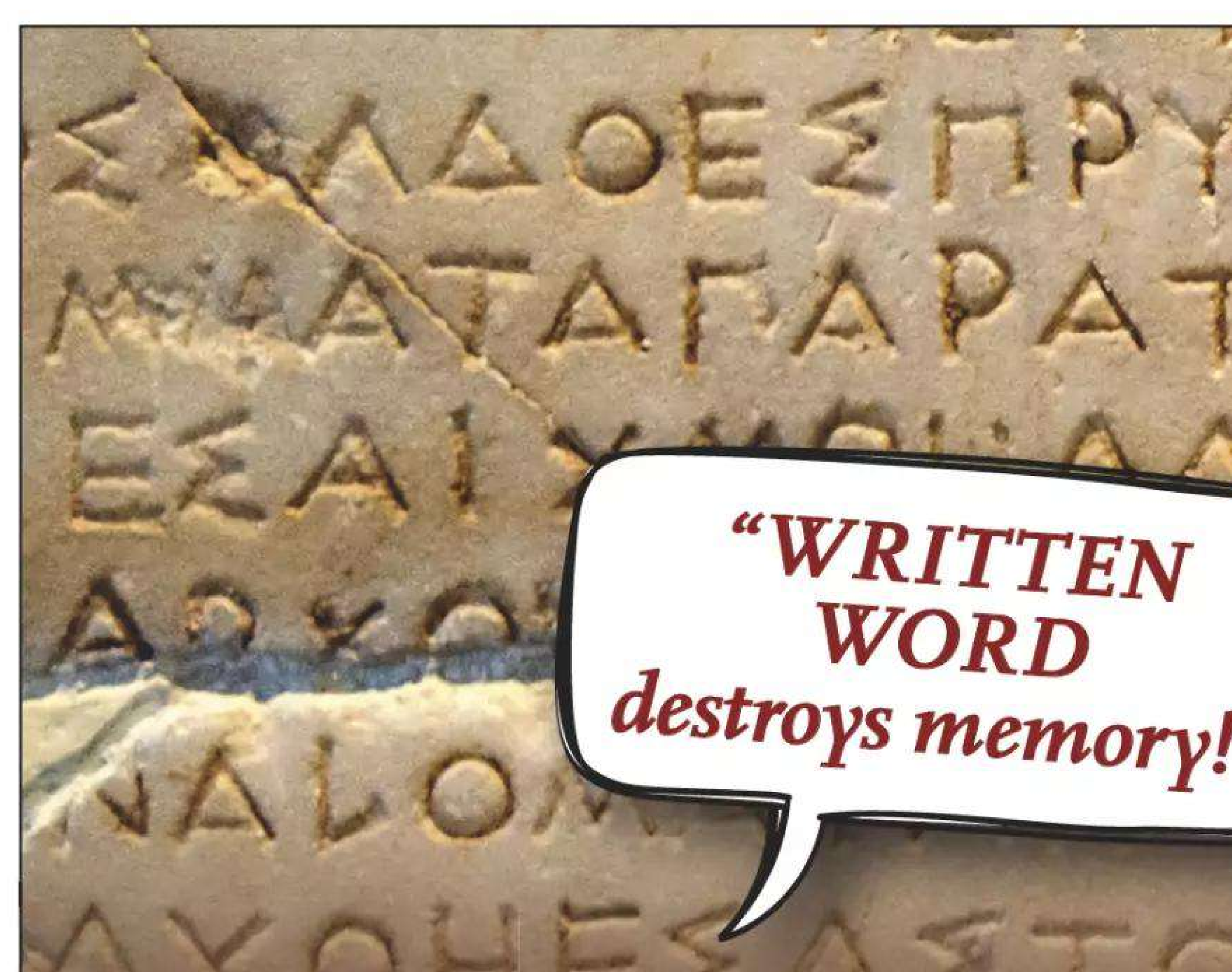
Post offices had special counters for women to prevent them from having contact with men.

GETTY IMAGES

Low postage cost triggered scandal

IN 1845, postage in the United States was reduced to three cents, enabling most people to afford to send a letter. Women from all walks of life now flocked to post offices, where they could send and receive letters without the supervision of their fathers and husbands.

For men, the post office became a source of fear that women’s virtue was being violated: “[Post offices] are the favourites of intriguers of both sexes, and are frequently made rendezvous for interdicted communication and illicit pleasures,” journalist Junius Browne wrote about New York’s post offices in 1869.



SHUTTERSTOCK

“WRITTEN WORD destroys memory!”

Socrates warned against the written word

ANTIQUITY’S greatest philosopher, the Greek Socrates (469-399 BC), detested the written word – and was reluctant to pick up a stylus. Fortunately, the philosopher’s student, Plato, wrote down his teacher’s words. This is the only reason historians know that Socrates considered the written word to be passive, and compared it to a painting – both “stand before us as though they were alive; but if you question them, they maintain a most majestic silence”.

And because writing is static and does not come from within, like speech, it can’t be used to gain insight or impart new knowledge. Writing can only remind us of what we know. This is a danger, because the written word weakens our memory and will “instil forgetfulness in the soul, because the power of memory will not be exercised,” Socrates stated.

GETTY IMAGES

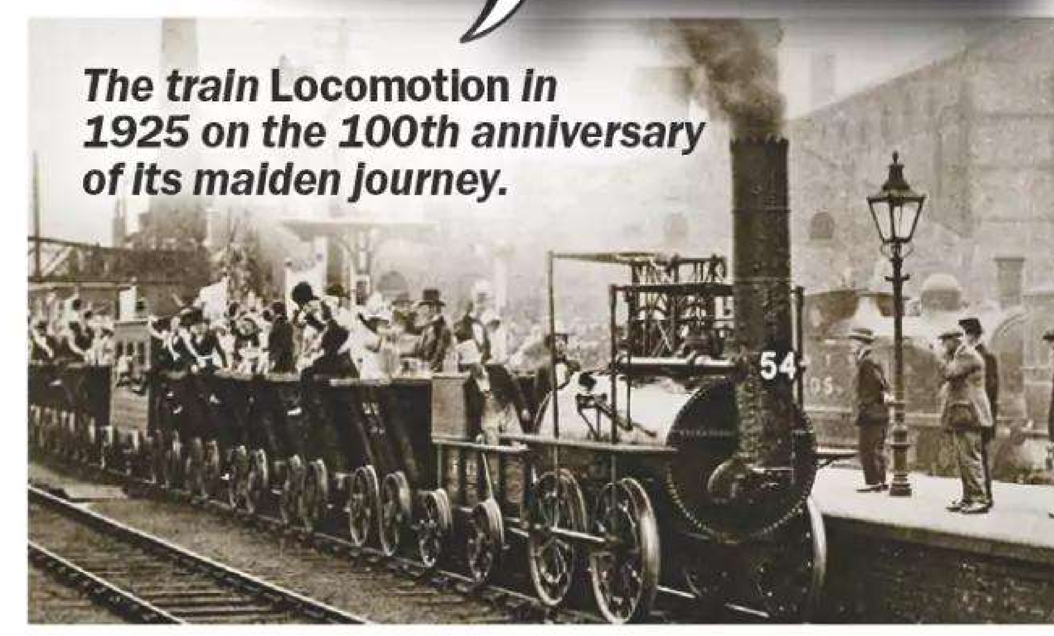
“MODERN MUSIC poisons the ear!”

The Pope thundered against monks’ new polyphonic music in the Middle Ages.

New music offended the Church

IN THE 12TH CENTURY, the monks of Notre-Dame in Paris began experimenting with melodies, harmonies and rhythm. The new music – known as mensural – gave instruments and voices the freedom to flow more independently of each other, but also caused outrage. In 1324, Pope John XXII issued a decree thundering against the monks and forbidding their music: “The great number of notes in their compositions conceals from us the plainchant melody, with its simple well-regulated rises and falls that indicate the character of the church mode,” the Pope wrote, and went on: “These musicians … intoxicate the ear without satisfying it; they dramatise the text with gestures; and, instead of promoting devotion, they prevent it by creating a sensuous and indecent atmosphere.”

“TRAIN will suffocate passengers!”



The train Locomotion in 1925 on the 100th anniversary of its maiden journey.

IMAGESELECT

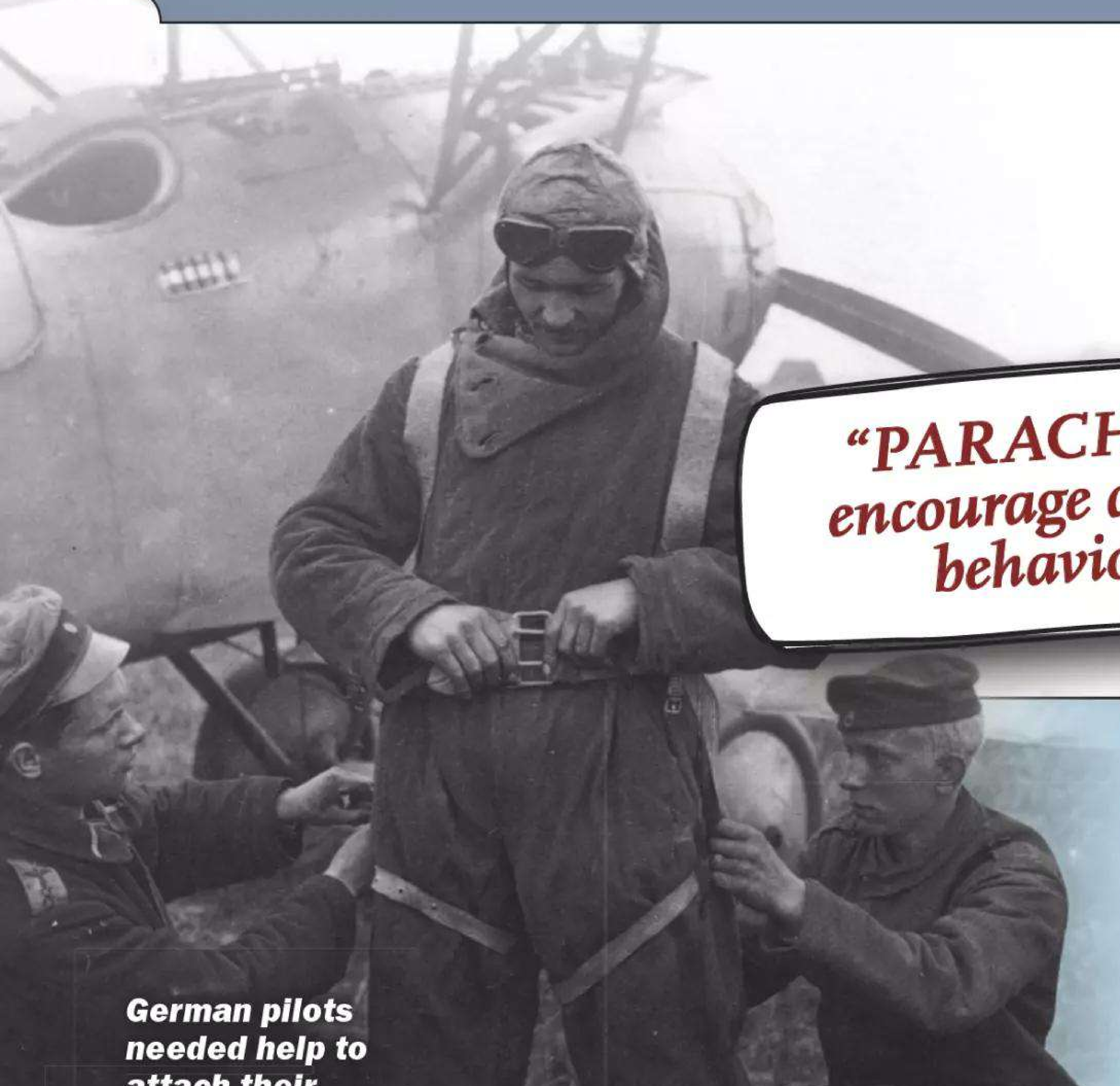
Steam locomotives gave sceptics nightmares

IN 1825, passengers travelled on a train pulled by a steam locomotive on a public railway for the first time. The journey in the north of England was when most people walked or travelled by horse-drawn carriage, so with a top speed of 24 km/h, the steam locomotive was a speed demon. Sceptics said that trains would cause milk to sour in cows’ udders and grain to spoil in the fields, or that passengers would suffocate from a lack of oxygen or their bodies would burst.

“CINEMA leads our children astray!”

Kids lured to depravity

IN 1909, a US child protection group wrote: “Depraved adults with candies and pennies beguile children with the inevitable result. [This] society has prosecuted many for leading girls astray through these picture shows, but God alone knows how many are leading dissolute lives begun at the ‘moving pictures.’” The criticism concerned the latest phenomenon: cinema.



German pilots needed help to attach their parachute.

IMAGESELECT

“PARACHUTES encourage cowardly behaviour!”

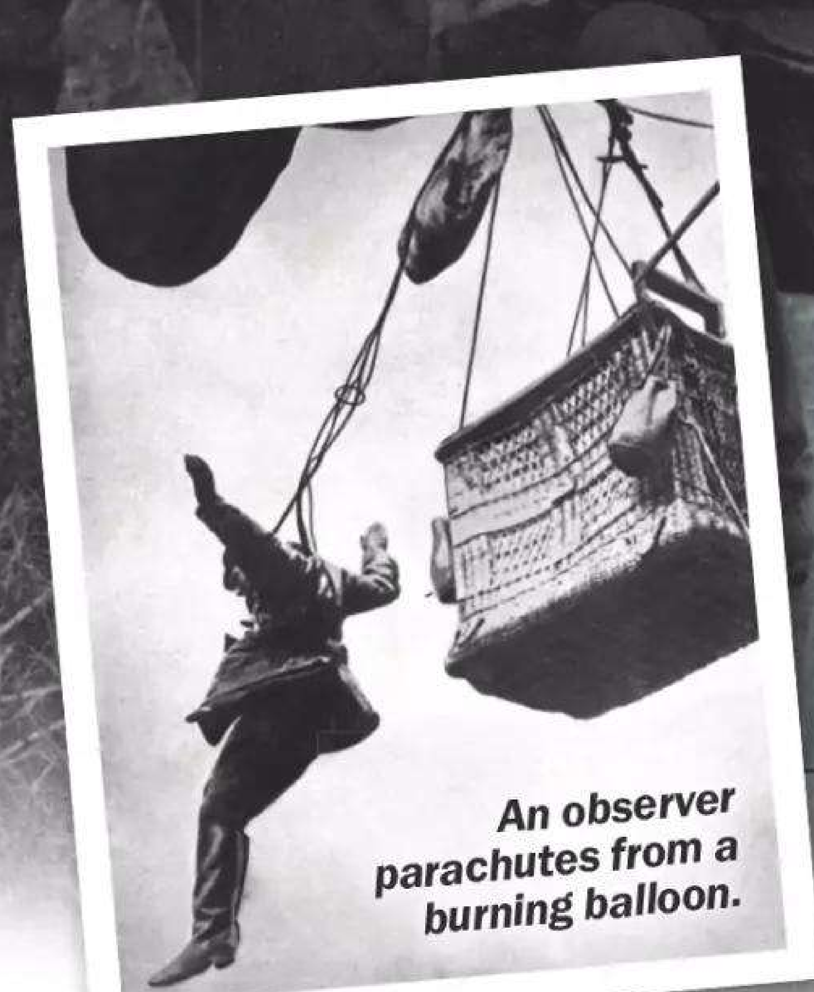
Pilots sent into combat with no chance of saving their lives

WORLD WAR I fighter planes were slow and easy to hit. Fighter pilots could not expect to fly for more than a few weeks before being shot down.

To save pilots – so they could continue to participate in the war – the Germans introduced parachutes, but the enemy was dismissive. British pilots were banned from using parachutes because, according to the Air Ministry, they encouraged cowardly behaviour in combat. The argument was that if pilots could abandon their aircraft, they wouldn’t fight hard enough.

“Cannot help but feel that it was criminal negligence on the part of those higher up for not having exercised sufficient forethought and seeing that we were equipped with parachutes for just such emergencies,” US airman Eddie Rickenbacker wrote after losing two comrades.

British pilots were allowed to use parachutes in the final years of WWI, while Americans had to wait until after the war.



An observer parachutes from a burning balloon.

SHUTTERSTOCK

Printed works scared scholars

"BOOKS will send world into barbarism!"

The printer Gutenberg wasn't just praised for his printing press. Many believed that books would throw Europe into chaos and weaken monks' relationship with God.

SHUTTERSTOCK

THE 15TH-CENTURY saw the newly invented printing press make it easy to publish books in large numbers. More Europeans were able to buy books that had previously been expensive and scarce. However, this development was strongly criticised.

Among the opponents was Swiss naturalist Conrad Gessner (1516-1565), who in the 1540s compiled a list of all the books published using the printing press over the past 100 years. The list included 10,000 titles – a number that shocked Gessner. He believed that ordinary people could not handle that much knowledge, and that Europe's rulers should immediately regulate the trade in publications to prevent "the confusing and harmful abundance of books".

Gessner's views were shared by others, including French scholar and author Adrien Baillet (1649-1706), who wrote that the many new views in books would divide Europe: "We have reason to fear that the multitude of books, which grows every day in a prodigious fashion, will make the following centuries fall into a state as barbarous as that of the centuries that followed the fall of the Roman Empire."

Abbot Johannes Trithemius (1462-1516) of Würzburg in southern Germany was more concerned about the thousands of scribe monks who effectively lost their jobs because their work of copying books was taken over by the printing press.

"Of all manual labour nothing is more in accord with the state of monks than the zealous copying of sacred writings," stated Trithemius, who feared that in addition to their work, monks would lose their close relationship with God.

"He who ceases from zeal for writing because of printing is no true lover of the Scriptures," he appealed to the monks.

Printing press changed Europe for ever

With the invention of the printing press around 1450, books – and thus knowledge – became accessible to far more people. This development would have crucial consequences for Europe.

The Reformation might not have happened without the printing press. The technology enabled German monk Martin Luther to spread his rebellious ideas and gain support for his stand against the corrupt Pope.

Illiteracy decreased among Europeans as more people gained access to books. This broke the elite's monopoly on education and knowledge.

The middle class was created in Europe because, over time, more poor people gained access to education and thus better-paid jobs.

Latin died out as Europeans begun publishing books in their own languages – for example, Martin Luther translated the Bible into German.

Nationalism was slowly awakened as different peoples became more aware of their linguistic and cultural distinctiveness.

Science developed significantly as intellectuals recorded and shared their discoveries. In the 16th and 17th centuries, the world experienced a scientific revolution that laid the foundations of modern science.

Handwritten and coloured books were the domain of the Church for hundreds of years.

BRIDGEMAN IMAGES

Einstein

He was the most brilliant physicist of his time, but Albert Einstein had to fight for recognition. No university would hire him, and when he finally made a career for himself, the Nazi persecution of Jews began.

Switzerland/1905

Switzerland is a patchwork of peoples. German, French and Italian speakers live peacefully side by side. However, as in the rest of Europe, anti-Semitism lurked beneath the surface of this democratic country.

’s battle

The theory of relativity
resulted in one of the most well-known equations in physics: $E=mc^2$. The equation expresses the relationship between energy and mass.

At first, colleagues were sceptical. Then the Nazis took over and burned Einstein’s work.
COLLAGE: AOP/GETTY IMAGES, POLFOTO/GRANGER & SHUTTERSTOCK

BY JEPPE NYBYE

The famous physicist Lord Kelvin was adamant when he gave a speech to his colleagues in 1900:

"There is nothing new to discover in physics. All that remains is more and more precise measurement." Kelvin himself had led science to this point by establishing the theoretically lowest temperature possible – absolute zero. But just five years later, he would learn that scientists had still only uncovered a fraction of the secrets of physics. Because in 1905, an insignificant patent clerk from Bern challenged the laws of physics when he came up with the special theory of relativity.

Einstein made time relative

The 26-year-old Albert Einstein had long pondered a scientific dilemma as he and his colleague Michele Besso strolled through the streets of Bern towards their workplace at the patent office: he could not reconcile his theories about light with the facts, he told Besso.

Any little boy would say that if he ran fast enough, he would catch up with light. But Einstein realised that you could never catch up with light, no matter how fast you ran. Light would always be almost 300,000 kilometres per second faster than the pursuer. And Einstein found this phenomenon more than difficult to understand. "I'm going to give it up," he told Besso.

At that very moment, a thought struck Einstein and he found the key to the problem. The solution was to redefine the concept of time and forget the idea that time is absolute – the idea of a big ticking world clock. Instead, time is relative. This means that whoever chased light slowed down the pulse of their own time; in other words, time slows down for fast-moving things. Just five weeks later, the journal *Annalen der Physik* published an article in which Einstein explained his discovery and challenged over 200 years of accepted knowledge about space and time.

School rejected Einstein

If Einstein had expected to receive a standing ovation for his theory, he was to be sorely disappointed.

"His publication was followed by icy silence," his sister later remarked.

However, a select few – such as Europe's leading physicist, Max Planck – were quick to recognise Einstein's discovery as one of the most important in history. But beyond that, the response was muted. In fact, Einstein couldn't even get a job at a university.

In 1907, for example, Einstein applied for a position at the University of Bern as a *privatdozent* – an unsalaried teaching position and one of the lowest rungs

SPECIAL THEORY OF RELATIVITY **1905**

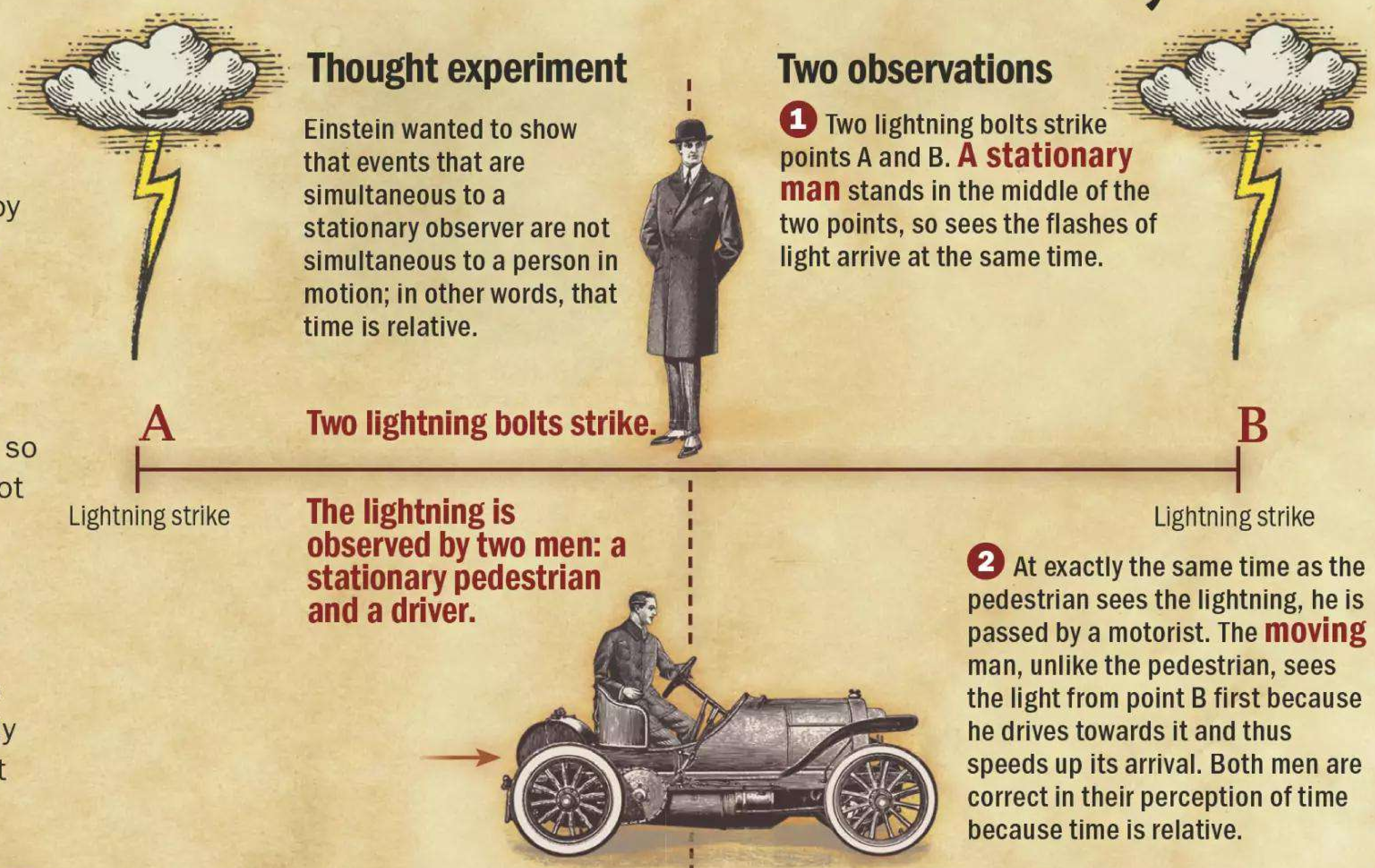
Time became relative with Einstein's theory

The theory of relativity challenged physicists' accepted world view.

The most famous scientific paper by Einstein also had one of the least interesting titles in history: 'On the Electrodynamics of Moving Bodies'.

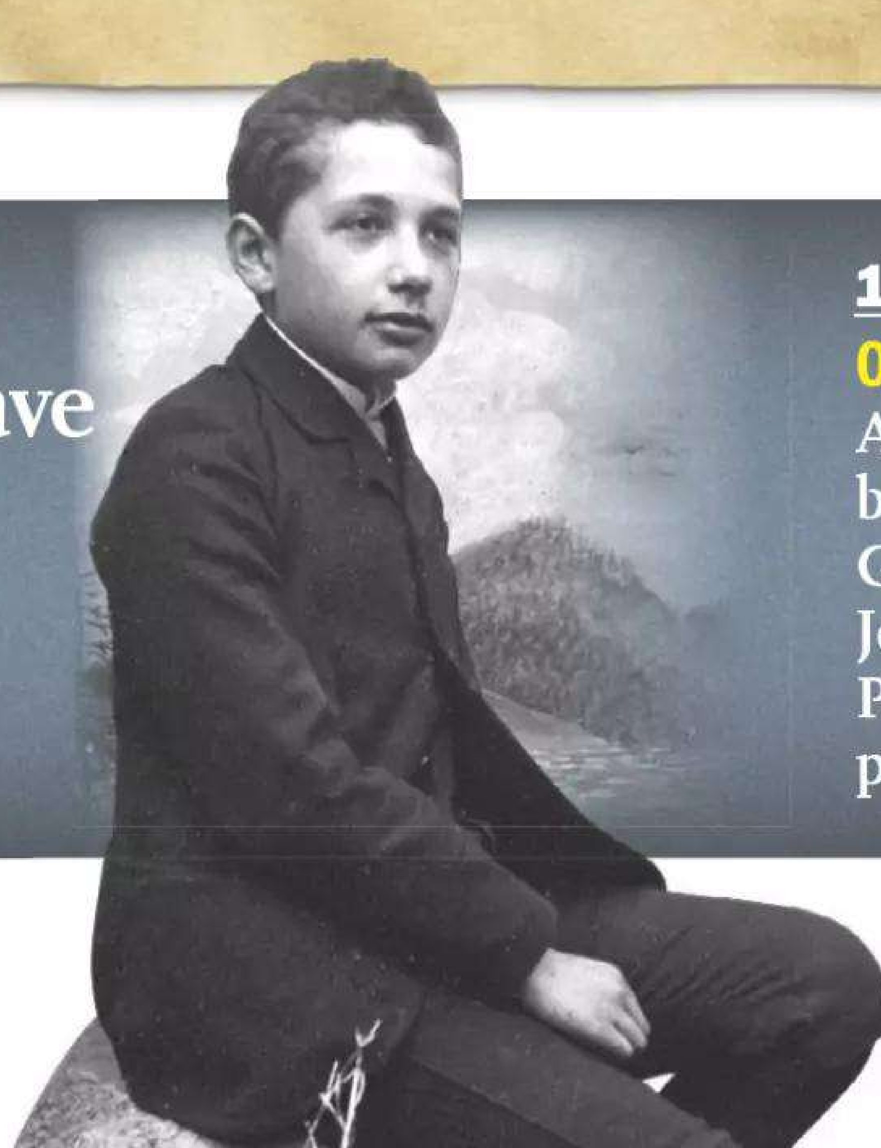
In it, he challenged one of the laws of physics by stating that time is not absolute – it is relative. The idea was so ground-breaking that the article did not contain a single reference to other scientific literature.

Einstein later explained his theory using a thought experiment (see illustration on the right). The theory is called special relativity because it only applies when the observer is either at rest or moving at a constant speed.



Einstein's life: from cradle to grave

Nazi persecution of Jews caused Einstein to leave Europe.



Einstein grew up in Germany. However, he renounced his citizenship twice.

POLFOTO/ULLSTEIN

1879
On 14th March, Albert Einstein is born in the southern German city of Ulm. Jews Hermann and Pauline are the proud parents.

1896
At the age of 17, Albert Einstein leaves school and enrols at Zurich Polytechnic. At the same time, he renounces his German citizenship because he hates German militarism.

1900
Einstein graduates from Zurich Polytechnic with a miserable grade.

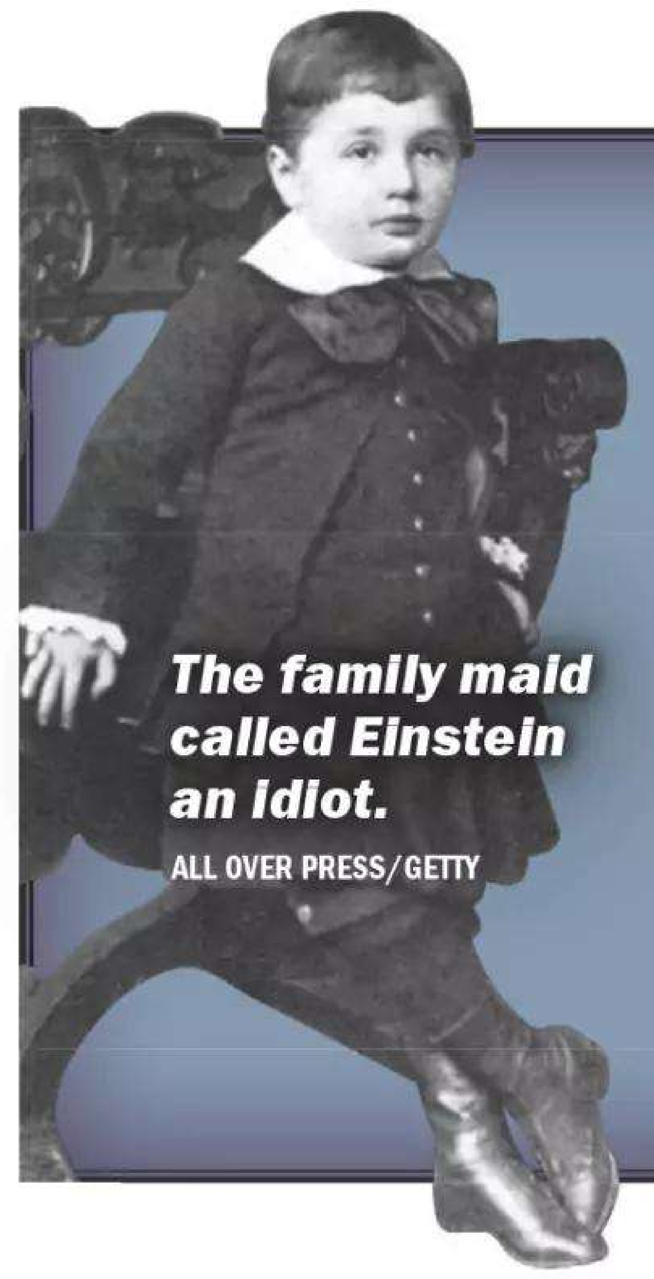
on the academic ladder. The hope was that the position would eventually lead to him becoming a professor. With his application, he sent 17 scientific papers – including one on the theory of relativity – while ignoring the requirement to also include an unpublished thesis. This requirement was often waived if the applicant had made "other outstanding achievements" – something Einstein could be said to have done.

Still, only one member of the hiring committee recommended taking him without the extra thesis. The rest stood firm, and Einstein didn't get the position.

The following year, he moderated his ambitions and applied for a job teaching maths at a school in Zurich.

"I would be ready to teach physics as well," Einstein wrote in his application. A total of 21 people applied for the position, but the world's smartest physicist didn't even make the shortlist of the top three candidates.

The school's somewhat surprising rejection prompted Einstein to swallow the last remnants of his pride and write a thesis to become a *privatdozent* in Bern – a position he obtained and held alongside his duties at the patent office.



The family maid called Einstein an idiot.

ALL OVER PRESS/GETTY

Young Albert was not too bright

1. As a child, Einstein had such difficulty speaking that he whispered to himself before daring to say anything out loud. The habit caused the family maid to call him *"der Depperte"* – the dopey one.

2. According to myth, Einstein failed maths at school. However, this is not true. Instead, Einstein's teacher at Zurich Polytechnic gave him a failing grade of 1 in Physical Experiments for Beginners, partly due to poor attendance.

3. Einstein ended up with an average of 4.9 at the polytechnic, putting him in the bottom quarter of his class.

Jewish background was obstacle

Einstein finally got his foot in the door of academia, but his struggle continued. When he tried to become an assistant professor at the University of Zurich in 1909, physics professor Alfred Kleiner had to assure his colleagues that Einstein was acceptable, despite being Jewish.

"The expressions of our colleague Kleiner ... were all the more valuable ... since Herr Dr Einstein is an Israelite and since precisely to the Israelites among scholars are inscribed ... all kinds of unpleasant peculiarities of character, such as intrusiveness, impudence and a shopkeeper's mentality," the hiring committee wrote in its report, and chose to trust Kleiner's judgement.

For the next two years, students in Zurich were able to benefit from Einstein's unusual teaching style: he had scribbled down his notes on a postcard, for example, and after lectures he would invite his students to join him in a café.

Although Einstein was well liked by his students, his Jewish background was again an obstacle when he wanted to take another step up the ladder in 1911. The University of Prague had offered him the professorship he wanted so badly. But then the Ministry of Education stood in his way.

Einstein had received some fine recommendations. Max Planck, for example, wrote to the ministry saying that Einstein's special theory of relativity had "brought about a revolution" in the physical world view. Nevertheless, the ministry decided in favour of another candidate, Gustav Jauman, for the job. His ▶

Theories divided physicists

Einstein's theories of relativity were controversial and some physicists criticised them vehemently. The most prominent critic was Nobel Prize winner Philipp Lenard, whose attacks were downright anti-Semitic. On the other hand, Einstein received support from the foremost physicist of the time, Max Planck, who offered advice and support.

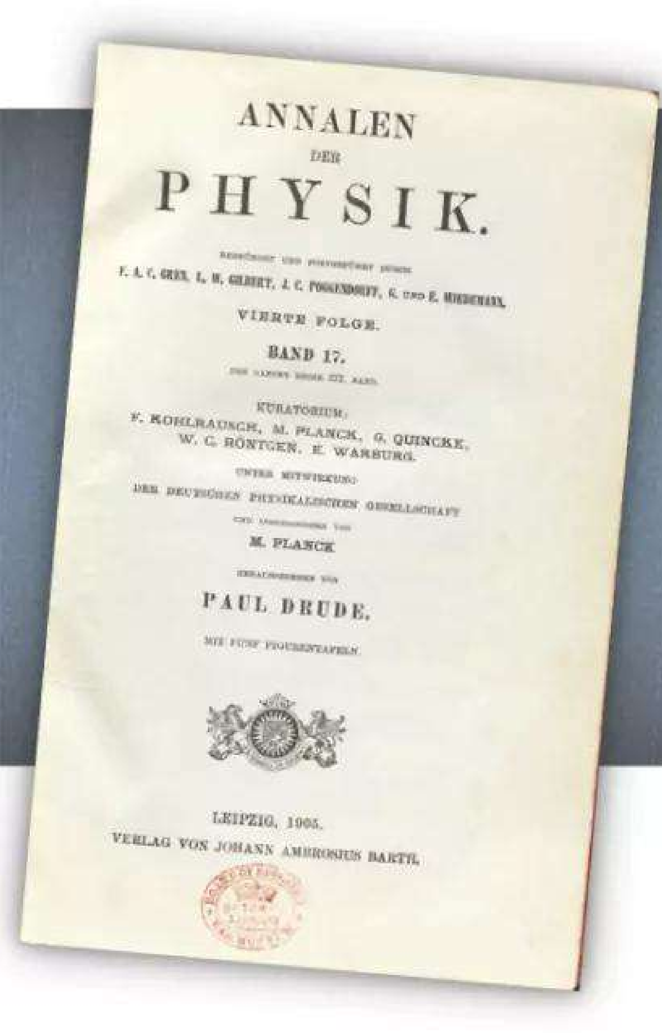
Friend Max Planck

Opponent Philipp Lenard

SCANPIX/SPL & POLFOTO/GRANGER

1902
The patent office in Bern hires Einstein. There he assesses patent applications.

1903
Einstein gets married.



The cover of the scientific journal featuring Einstein's theory.

ALL OVER PRESS/GETTY

1905
Einstein's special theory of relativity is published in the journal *Annalen der Physik*. He attaches the theory to a later famous equation: $E=mc^2$.

1908
The University of Bern hires Einstein as a *privatdozent.*

1909
Patent office receives Einstein's resignation when he is appointed assistant professor at the University of Zurich.

1911
Einstein is a professor when he transfers to the University of Prague.

major qualification was that he was not Jewish.

"I did not get the call to Prague. I was proposed by the faculty, but because of my Semitic origin the ministry did not approve," Einstein wrote in a letter to a friend shortly afterwards. However, he was to receive help from an unexpected quarter. When Gustav Jauman learned that he had been chosen at Einstein's expense, he was furious and refused the professorship.

"I will have nothing to do with a university that … does not appreciate merit," he announced. Despite all the difficulties, Einstein was finally able to call himself a professor. The struggle to get to that position had lasted six years since he had come up with the theory of relativity.

While Einstein was reviled in Germany, he was hailed as a hero in the US.
SCANPIX/AKG

Theories triumphed around world

During the following years, Einstein did well in academia, and in 1914 he landed a dream position at the University of Berlin as head of department.

One of the things that particularly concerned Einstein during this period was the shortcomings of his special theory of relativity. For example, he couldn't get gravity to fit into the picture In 1916, he solved the problem. In his theory of general relativity, he established that gravity deflects light, so stars appear as though they are somewhere other than where they actually are.

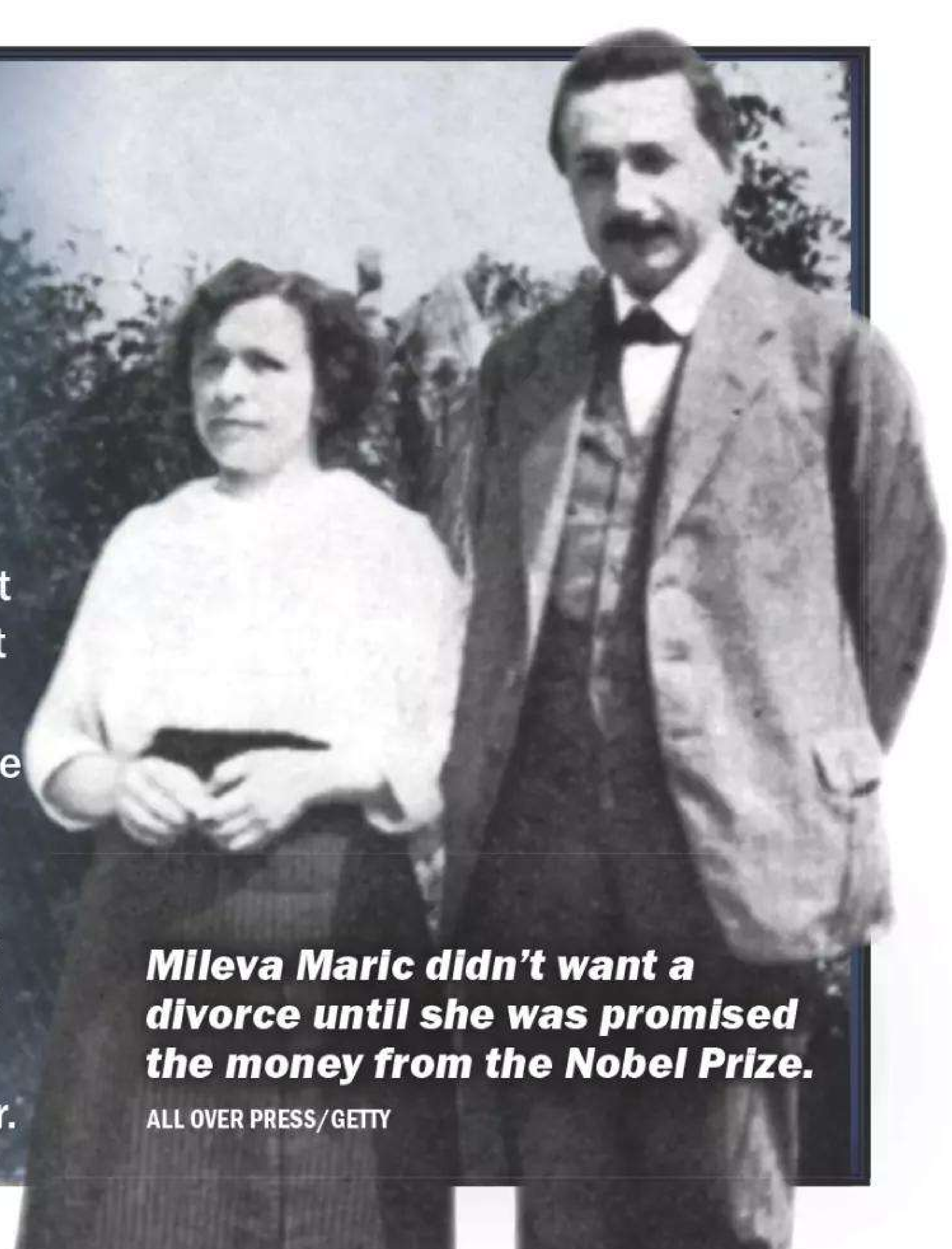
Einstein's new general theory of relativity also challenged centuries-old notions of space and time, but only became widely known in scientific circles after the end of World War I. However, when the consequences of the theories of relativity were recognised, the media went crazy and elevated Einstein to celebrity status. The *New York Times,* for example, ran a six-deck headline to publicise the discovery:

"Einstein theory triumphs: Stars not where they seemed or were calculated to be, but nobody need worry," read part of the headline.

Ex-wife got Nobel Prize money

Albert Einstein desperately tried to divorce his first wife Mileva Maric – something she refused to do. In the end, Einstein was forced to promise the money from the Nobel Prize in exchange for a divorce. He had not yet won the prize, but he was convinced it was only a matter of time.

Mileva Maric had to wait a long time for the money. It wasn't until 1922, three years after the divorce, that Einstein was awarded the Nobel Prize and a sum of approximately 120,000 Swedish krona – equivalent to ten times the annual salary of a professor.



Mileva Maric didn't want a divorce until she was promised the money from the Nobel Prize.
ALL OVER PRESS/GETTY

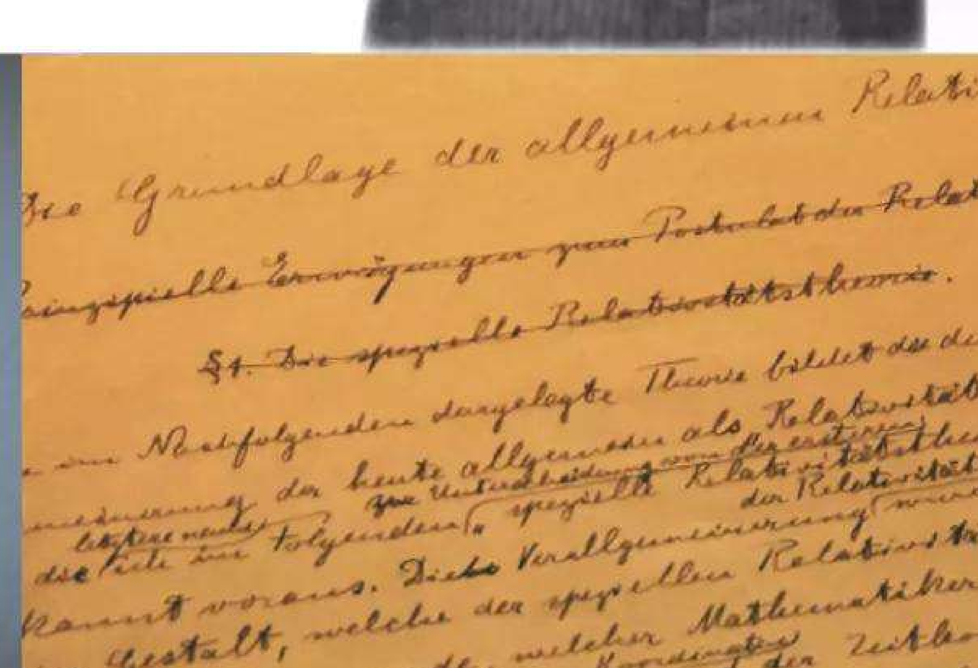
Nazis sabotaged Einstein

However, Einstein's new status also had a downside. In Germany, anti-Semitism began to grow due to the defeat in World War I, and Einstein became a symbol of the hated Jews for many. For example, some nationalists formed the Study Group of German Scientists for the Preservation of Pure Science, which directed several attacks against the "Jewish nature" of Einstein's theories.

In August 1920, the group organised a meeting in Berlin where a number of scientists called his theories a hoax. In the middle of one of the speeches, there

1914

The same year as WWI begins, Einstein moves to Berlin, where he has been selected as a member of the Prussian Academy of Sciences. Einstein resumes his German citizenship.



General relativity took up 50 handwritten pages. Here are the opening lines of the document.
ALL OVER PRESS/GETTY

1915

Einstein finalises the general theory of relativity, which takes into account special relativity's shortcomings. The following year, it is published, but due to WWI, many overlook the discovery.

1919

In February, Einstein and his wife divorce after years of war on the domestic front. He marries his cousin Elsa instead. That same year, the general theory of relativity is proven when a solar eclipse

GENERAL THEORY OF RELATIVITY

1916

Space is curved

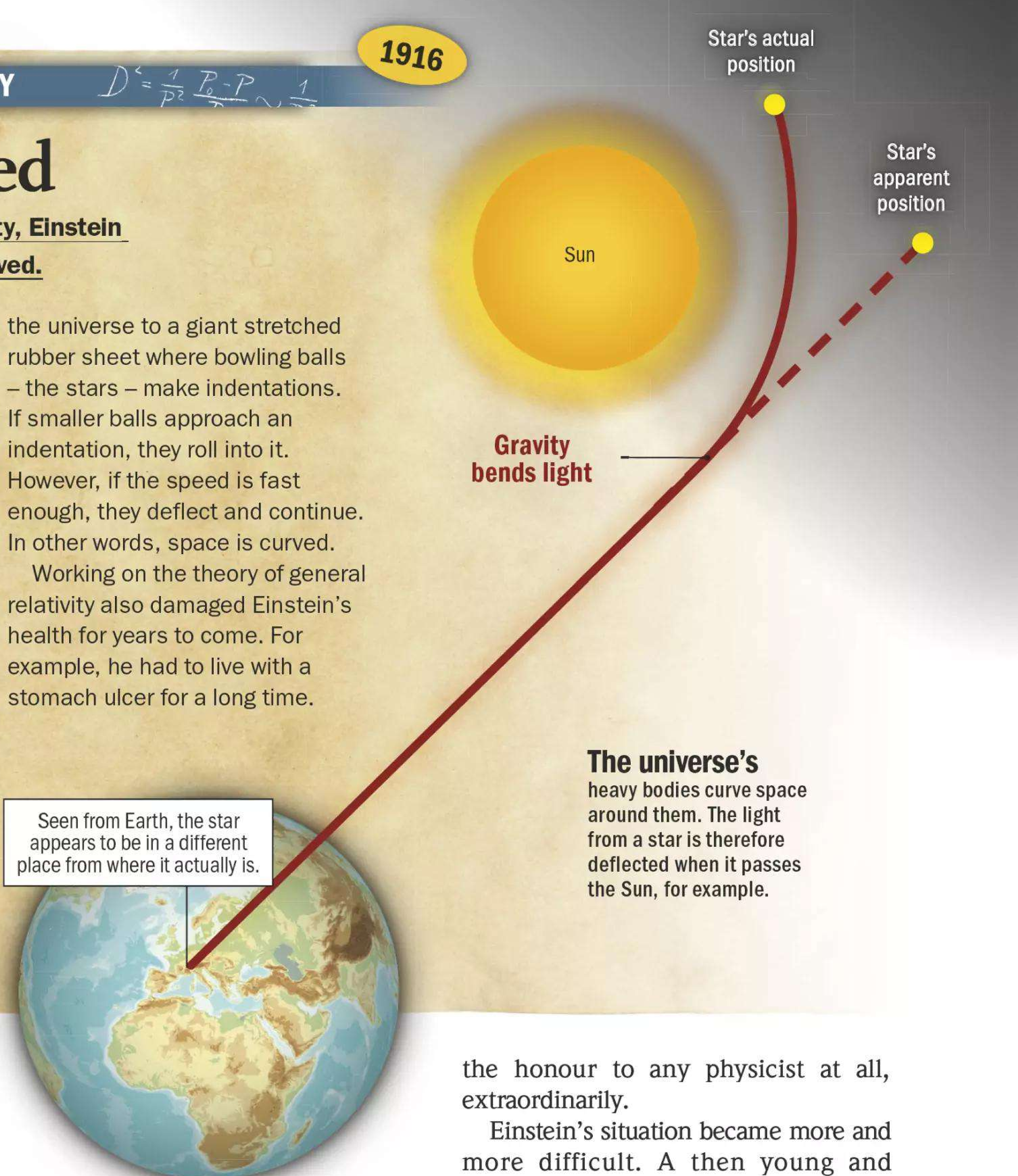
With the general theory of relativity, Einstein claimed in 1916 that space is curved.

Einstein had been struggling with the shortcomings of the special theory of relativity since its discovery in 1905. But two years later, he finally made a breakthrough – something he called "the happiest thought in my life".

It wasn't until 1916, however, that he completely finalised his general theory of relativity.

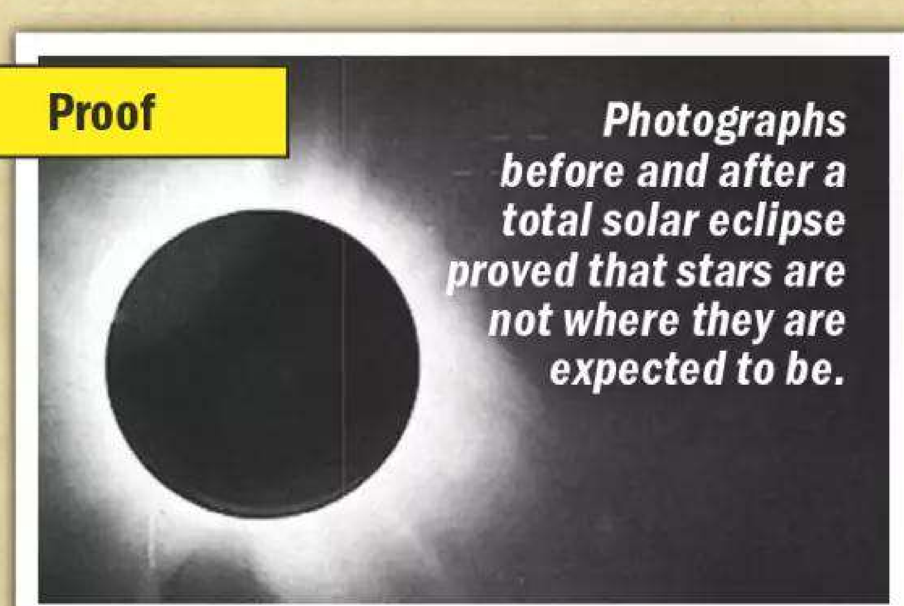
When he later explained his theory to journalists, he compared the universe to a giant stretched rubber sheet where bowling balls – the stars – make indentations. If smaller balls approach an indentation, they roll into it. However, if the speed is fast enough, they deflect and continue. In other words, space is curved.

Working on the theory of general relativity also damaged Einstein's health for years to come. For example, he had to live with a stomach ulcer for a long time.



The universe's heavy bodies curve space around them. The light from a star is therefore deflected when it passes the Sun, for example.

Proof



Photographs before and after a total solar eclipse proved that stars are not where they are expected to be.

ROYAL SOCIETY OF LONDON

was suddenly a quiet murmur from the audience: "Einstein, Einstein."

He was at the meeting and from his seat he chuckled at their absurd claims.

However, he wasn't that amused. In fact, he was angry, and shortly afterwards he wrote an article for the *Berliner Tageblatt* newspaper in which he criticised the association and its supporters. One of whom, 1905 Nobel Prize winner Philipp Lenard, was particularly enraged by the article. He responded with a series of venomous attacks on Einstein and "Jewish science". For example, Lenard advocated the creation of an association called Deutsche Physik, whose goal was to cleanse German physics of Jewish influence.

Behind the scenes, Lenard also tried to prevent Einstein from winning the Nobel Prize in Physics. For example, he contacted Swedish scientist Sven Hedin, who was part of the committee that awarded the prestigious prize, and tried to convince him that "relativity was really not a discovery". Lenard's crusade apparently worked. In any case, the 1920 Nobel Prize went to somebody else, and the following year the committee failed to award the honour to any physicist at all, extraordinarily.

Einstein's situation became more and more difficult. A then young and unknown member of the German Nazi Party, for instance, began to sound like Lenard's echo.

"Science, once our greatest pride, is today being taught by Hebrews," Adolf Hitler wrote in a letter to a newspaper. And later, Einstein was warned that his name was on a list of assassination targets. He had to leave Berlin.

"The newspapers have mentioned my name too often, thus mobilising the rabble against me," he wrote to Planck.

The months following the police warnings were gruelling for Einstein.

"I'm always on the alert," he complained to a friend. In the midst ▶

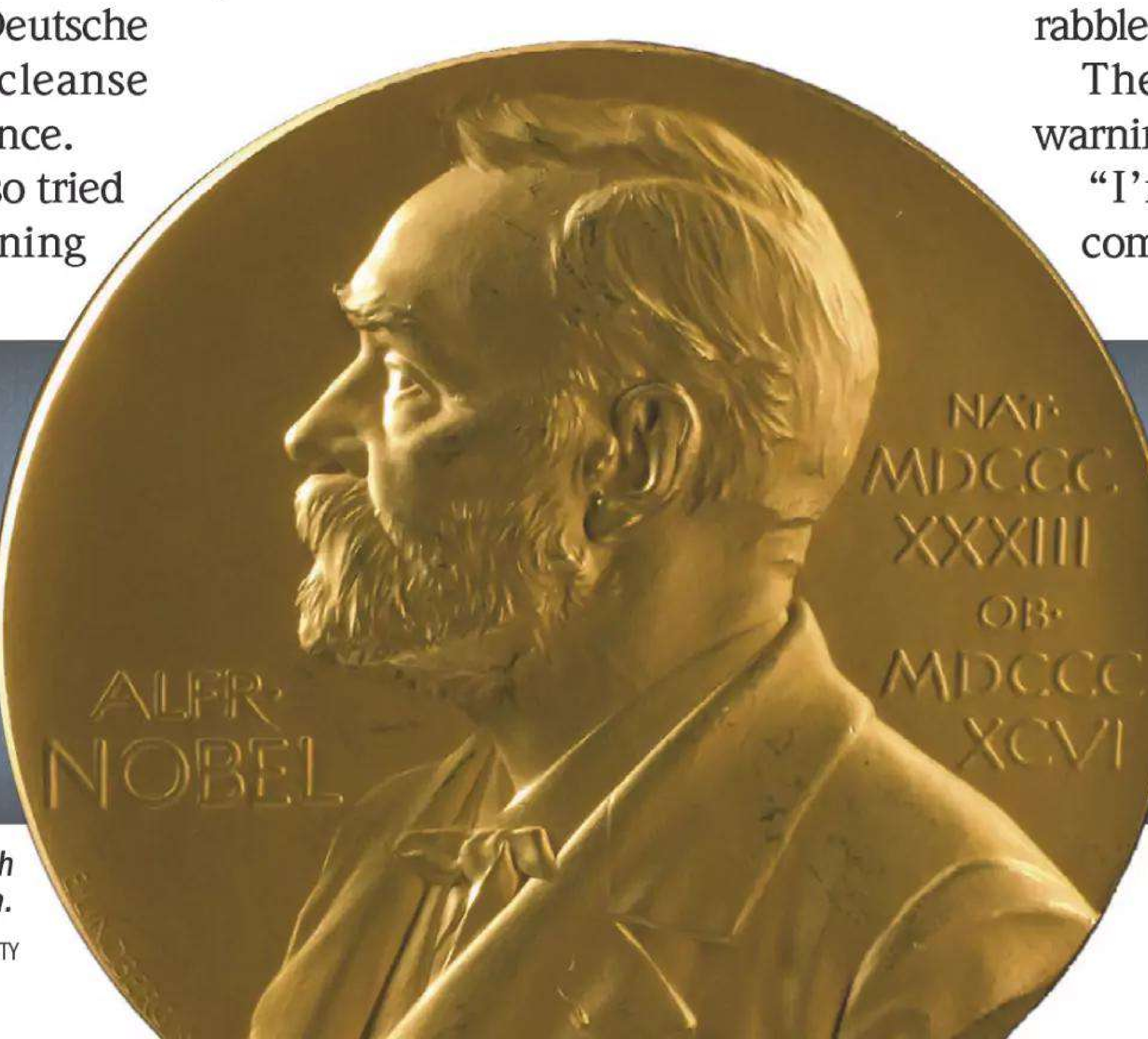
makes it possible to observe the true position of the stars.

1922

After ignoring Einstein for so long, the Royal Swedish Academy of Sciences finally awards him the Nobel Prize in Physics. But he does not get it for his theories of relativity.

1932

Einstein leaves Germany to devote himself instead to foreign visiting professorships.



The Nobel Prize came with a cash prize of 120,000 Swedish krona.

ALL OVER PRESS/GETTY

of the crisis, however, Einstein was delighted to finally win the Nobel Prize in Physics. Ignoring Einstein had become too embarrassing for the Nobel Committee. However, the committee could not admit that it had been wrong about the theory of relativity, so as a compromise, Einstein was awarded the prize for one of his other theories. The Nobel Committee received only one protest – from Lenard. In a letter, he wrote that Einstein was an attention-seeking Jew whose methods were alien to the spirit of German physics.

Einstein fled from Hitler

Hitler's Nazi party grew and finally came to power in January 1933. Einstein had left the country a month earlier to devote himself to visiting professorships abroad. But he had always believed he could return. That was now impossible.

"Because of Hitler, I don't dare step on German soil," Einstein wrote.

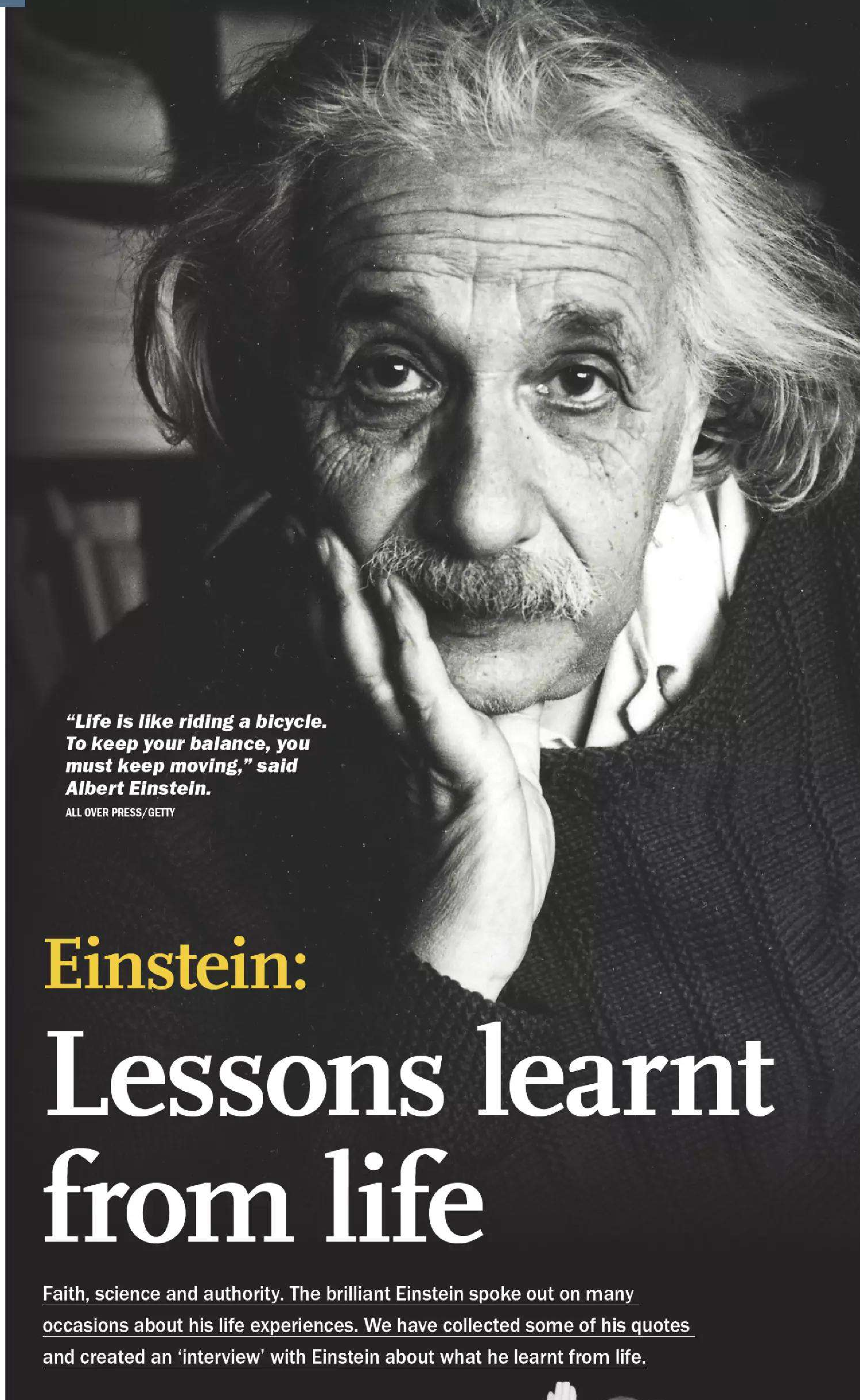
With good reason, as it turned out. In Einstein's absence, Nazi thugs searched his apartment five times. His house outside Berlin was also searched on the pretext that it was a communist armoury.

In March 1933, this event prompted Einstein to hand in his passport at the German consulate in Brussels and renounce his German citizenship.

His homeland wanted nothing to do with him either. In May 1933, around 40,000 Germans gathered in front of the Berlin Opera House to burn Jewish books – including Einstein's works. Later, a German magazine depicted him with the caption "not yet hanged".

On 7th October 1933, Einstein had had enough. He boarded the ocean liner *Westmoreland* and sailed to America. Although he lived for another 22 years, he never saw Europe again.

Einstein was later instrumental in helping the Allies develop the atomic bomb. Lenard was appointed head of Aryan science until the Allies deposed him in 1945. He died shortly after the war.

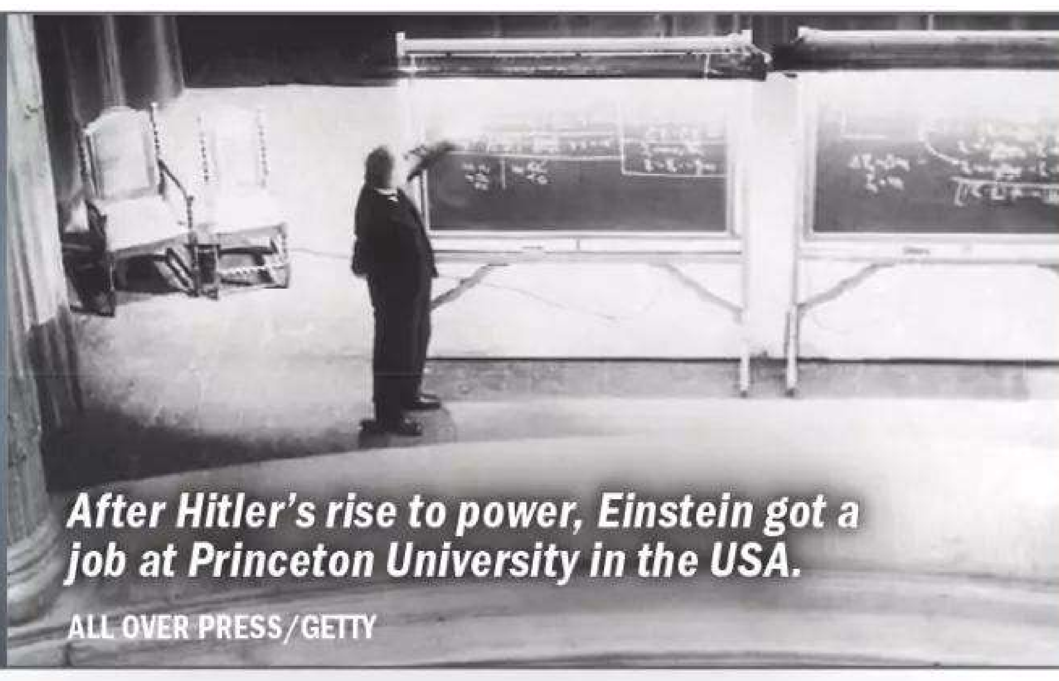


"Life is like riding a bicycle. To keep your balance, you must keep moving," said Albert Einstein.

ALL OVER PRESS/GETTY

Einstein: Lessons learnt from life

Faith, science and authority. The brilliant Einstein spoke out on many occasions about his life experiences. We have collected some of his quotes and created an 'interview' with Einstein about what he learnt from life.



After Hitler's rise to power, Einstein got a job at Princeton University in the USA.

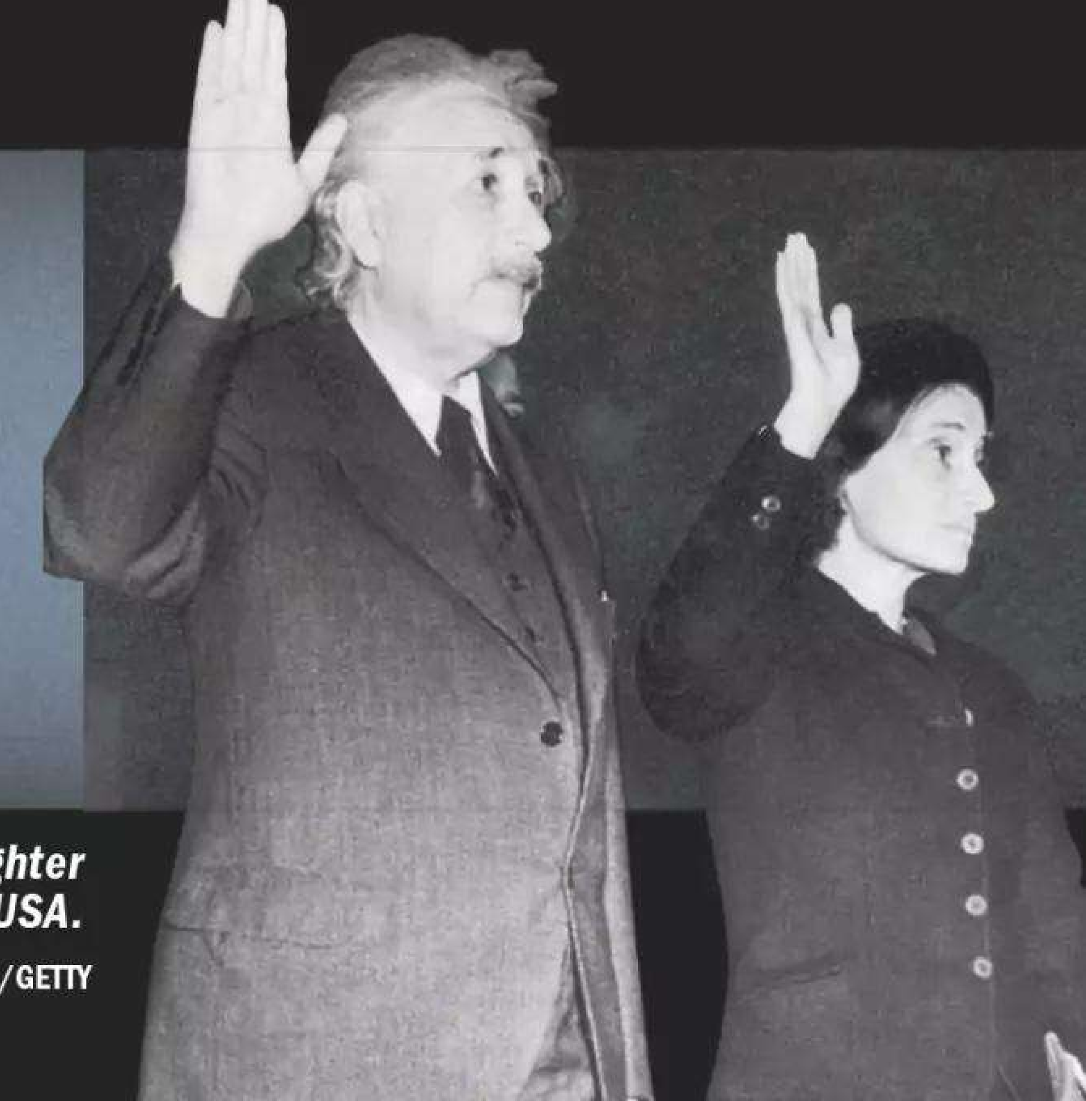
ALL OVER PRESS/GETTY

1933

Adolf Hitler is appointed chancellor of Germany in January. Einstein dares not return and renounces his German citizenship – again. In September, he emigrates to the USA, where he takes up a professorship at Princeton University in New Jersey.

1940

As World War II rages in Europe, Einstein becomes an American citizen.



In 1940, Einstein and his stepdaughter swore allegiance to their new country, USA.

ALL OVER PRESS/GETTY

BY JEPPE NYBYE & ERIK BORK

“**I rarely think** in words at all. A thought comes, and I may try to express it in words afterwards.

When I ask myself how it happened that I in particular discovered the relativity theory, it seemed to lie in the following circumstance. The ordinary adult never bothers his head about the problems of space and time. These are things he has thought of as a child. But I developed so slowly that I began to wonder about space and time only when I was already grown up. Consequently, I probed more deeply into the problem than an ordinary child would have.

I discovered that nature was constructed in a wonderful way, and our task is to find out the mathematical structure of the nature itself. It is a kind of faith that helped me through my whole life.

Mozart’s music is so pure and beautiful that I see it as a reflection of the inner beauty of the universe itself. Of course, like all great beauty, his music was pure simplicity.

Since the mathematicians have grabbed hold of the theory of relativity, I myself no longer understand it.

My religiosity consists of a humble admiration of the infinitely superior spirit that reveals itself in the little that we can comprehend about the knowable world.

I see a pattern, but my imagination cannot picture the maker of that pattern. I see a clock, but I cannot envision the clockmaker.

The most beautiful emotion we can experience is the mysterious. It is the fundamental emotion that stands at the cradle of all true art and science … To sense that behind anything that can be experienced there is something that our minds cannot grasp … In this sense, and in this sense only, I am a devoutly religious man.

We are in the position of a little child entering a huge library filled with books in many languages. The child knows someone must have written those books. It does not know how. It does not understand the languages in which they are written. The child dimly suspects a mysterious order in the arrangement of the books but doesn’t know what it is. That, it seems to me, is the attitude of even the most intelligent human being toward God.

Smoke like a chimney, work like a horse, eat without thinking, go for a walk only in really pleasant company.

To punish me for my contempt of authority, Fate has made me an authority myself.

What is the meaning of human life? … To know the answer to this question means to be religious. You ask: does it make sense, then, to pose this question? I answer: the man who regards his fellow creatures as meaningless is not merely unhappy but hardly fit for life.

If we want to resist the powers that threaten to suppress intellectual and individual freedom, we must be clear what is at stake. Without such freedom there would have been no Shakespeare, no Goethe, no Newton.

The example of great and pure characters is the only thing that can produce fine ideas and noble deeds. Money only appeals to selfishness and always tempts its owners irresistibly to abuse it. Can anyone imagine Moses, Jesus or Gandhi armed with money bags?

The patriotic women ought to be sent to the front in the next war instead of the men. It would at least be a novelty … and besides, why should not such heroic feelings on the part of the fair sex find a more picturesque outlet than in attacks on a defenceless civilian?

I am not only a pacifist. I am a militant pacifist.

Even if only two per cent of those assigned to perform military service should announce their refusal to fight governments would be powerless, they would not dare send such a large number of people to jail.

To punish me for my contempt of authority, Fate has made me an authority myself.

A man who only reads the newspapers … reminds me of a very short-sighted man who is too ashamed to wear glasses. He is completely dependent upon the judgements and fashions of his age and he sees and hears nothing else. And what a man thinks independently … is in the best of cases, comparatively feeble and monotonous..

With fame I become more and more stupid, which of course is a very common phenomenon.

The dog is very smart. He feels sorry for me because I receive so much mail. That’s why he tries to bite the mailman.

Life is like riding a bicycle. To keep your balance you must keep moving.”

1943

Einstein had persuaded the US president a few years earlier to put all his efforts into inventing an atomic bomb. In 1943, he helps the navy create a mathematical principle for placing mines in Japanese harbours.

Einstein in discussion with one of the physicists who helped create the atomic bomb.

POLFOTO/GRANGER

1955

On 18th April, Albert Einstein dies at Princeton Hospital. He is 76 years old.

Einstein lived to 76. His body was cremated and his ashes scattered in an unknown location.

ALL OVER PRESS/GETTY

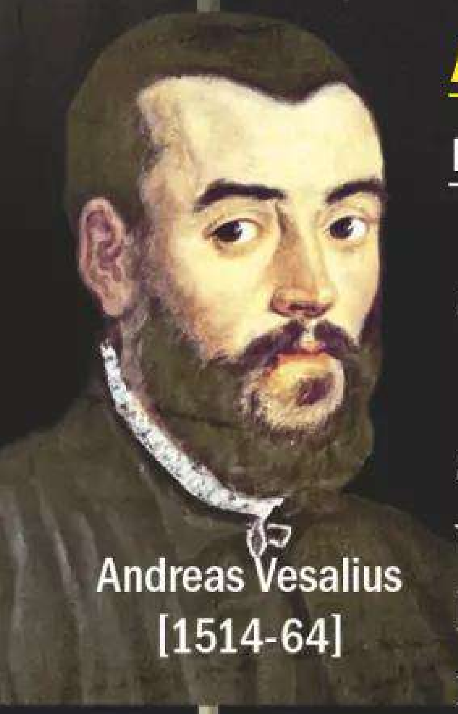
Under the knife

Four men paved the way for modern surgery

As a professor of anatomy, Vesalius shared his new, groundbreaking knowledge with the next generation of surgeons.
BRIDGEMAN

ANATOMY
Flanders, 1536

Skeleton on the kitchen floor founded modern anatomy



Andreas Vesalius [1514-64]
BRIDGEMAN

ANDREAS VESALIUS | By studying rotting corpses, a young medical student reversed 1,400 years of outdated knowledge to found modern anatomy.

Twilight was falling as Andreas Vesalius approached the city walls of Leuven. He had been studying medicine in Paris for three years but was now on his way to the Belgian city to complete his studies.

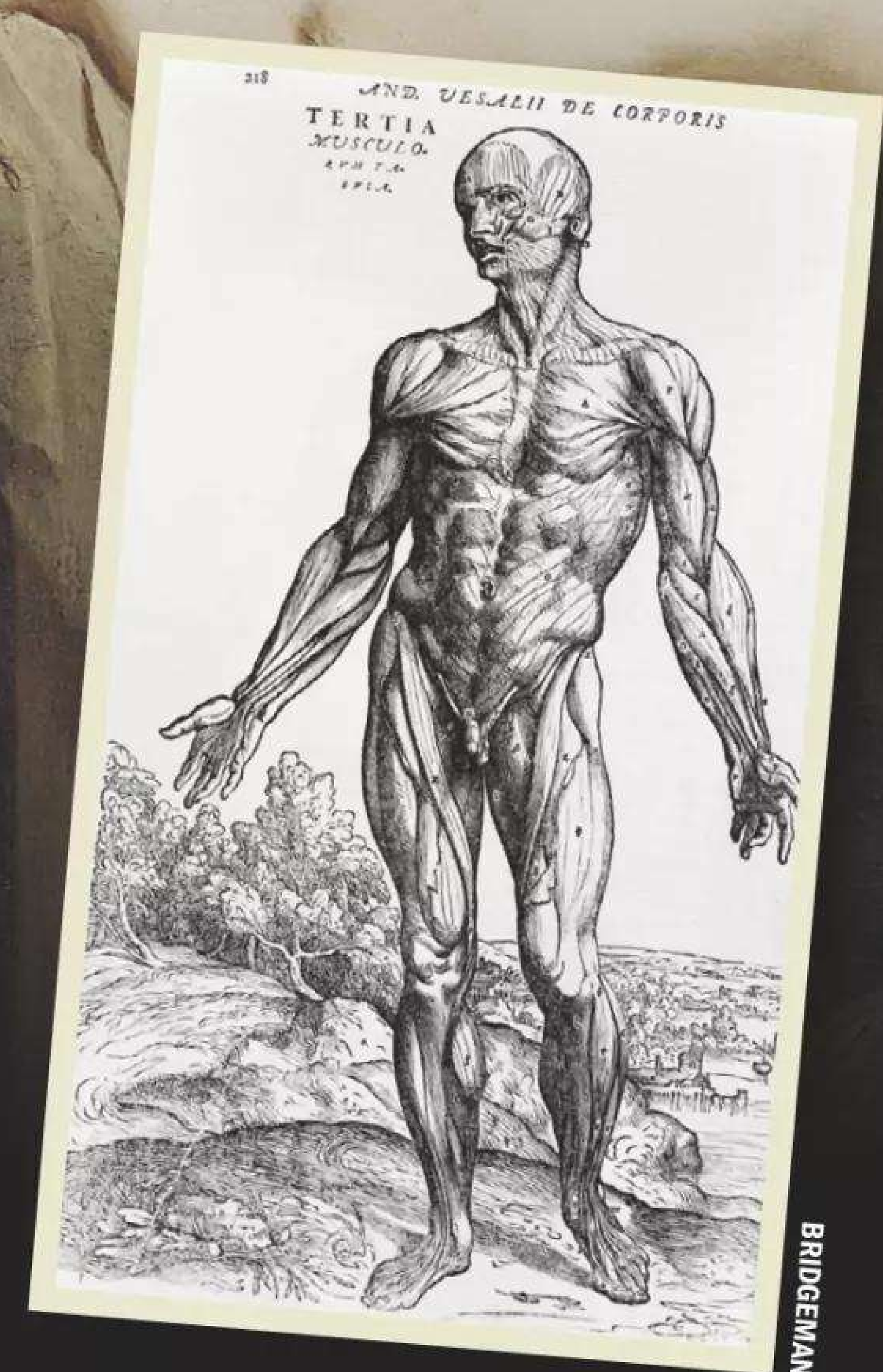
A shadow caught his eye. At the side of the road, he saw the silhouette of a dead criminal swinging on the city gallows. Vesalius quickly realised he could not let this opportunity pass him by. The corpse was already decomposing, so all he had to do was yank hard on one leg before it separated from the body. The other leg and arms also came off quickly. Vesalius rolled the bones into his coat and hurried home.

The young man threw his find on the kitchen table and rushed back out to the city gate to recover the hanged criminal's head and body.

Vesalius worked all night. He scraped the bones clean with a knife and threw the rotten meat scraps into the gutter. The bones were placed into a large vat of boiling water and when the sun had risen, a pile of clean bones lay on the kitchen floor. Vesalius assembled them into a skeleton and proudly looked at his masterpiece, even though both kneecaps and one foot were missing.

Gravediggers sold corpses

Before the theft of the hanged criminal, Vesalius – like other medical students of the time – had been studying the anatomical texts of the Roman physician Galen. But Vesalius suspected that the 1,400-year-old studies – which were a standard part of the

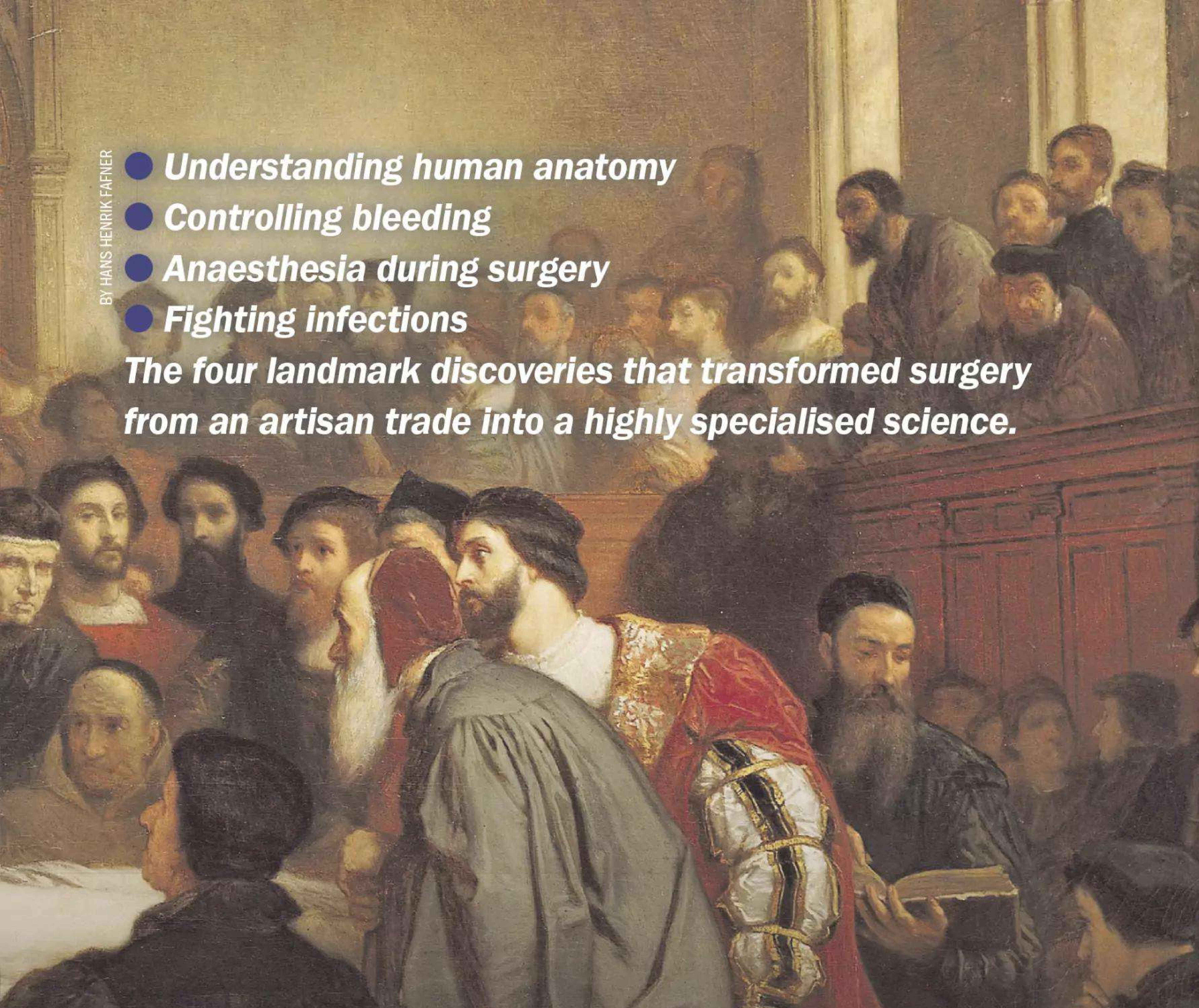


BRIDGEMAN

Vesalius's book from 1543 is filled with detailed drawings of the human body.

curriculum at European universities – were based on the dissection of animals.

After constructing his skeleton, his suspicions were confirmed, and in the coming years Vesalius studied as many bodies as possible. He became a regular in cemeteries, bribing gravediggers to hand over the dead. Vesalius collected his records in his



BY HANS HENRIK FAFNER

- Understanding human anatomy
- Controlling bleeding
- Anaesthesia during surgery
- Fighting infections

The four landmark discoveries that transformed surgery from an artisan trade into a highly specialised science.

BEFORE VESALIUS *Pergamon, 2nd century AD*

Galen set the standard for 1,400 years

Roman physician Galen began his career as a physician to gladiators in the Greek city of Pergamon, where he stitched their bodies back together after their bloody battles. Galen used this job as a springboard to pursue his true interest: anatomy.

In the Roman Empire, human dissection was forbidden, so Galen primarily based his studies on monkeys and pigs, which he believed were the closest to the human physique. He identified the internal organs – but mistook their placement and function. For example, Galen believed that the heart produced dark blood and the liver produced light blood. Nevertheless, Galen's studies formed the core of medical knowledge in Europe until the 16th century.

MARY EVANS

Galen worked as a gladiatorial surgeon, where his knowledge of anatomy came into its own.

seven-volume work *On the Structure of the Human Body*.

Vesalius corrected over 200 errors in Galen and confirmed that the great ancient anatomist had dissected animals. At the same time, Vesalius described all 206 bones in the body and created accurate drawings of the internal organs, which were now also arranged correctly in relation to each other.

When Vesalius was appointed professor of surgery and anatomy in the Italian city of Padua in 1537, he took another step towards modern surgery. Previously, university teaching had consisted of the professor going through Galen theoretically while an assistant simultaneously dissected an animal. Vesalius, on the other hand, wielded the knife himself and allowed his students to participate in the dissection. He thus established the principle that all surgery should be learned through the practical application of holding the body's organs in one's hands.

SURGERY'S LONG & WINDING ROAD

From evil demons to robots that can operate, the path to modern surgery has been a long one.

6500 BC

WELLCOME LIBRARY LONDON

Cave paintings show that Stone Age people sought to cure migraines with **trepanning**. According to historian Don R Brothwell, a hole was drilled in the skull to let out "evil air". Archaeological evidence suggests that half the patients survived treatment.

4000 BC

The earliest known surgeon was Urlugaledin of Sumer. He believed the most important surgical tool was knowledge of over **6,000 demons**, from which all diseases originated. Urlugaledin's emblem, which has been found on clay tablets, was two knives surrounded by healing herbs.

1550 BC

UNIVERSITY OF OKLAHOMA

The Ebers Papyrus – a 110-page description of **Egyptian medicine** – lists 700 healing potions, describes eye and skin diseases, and diagnoses pregnancy and dementia. It also explains how to remove tumours and set broken bones.

600 BC

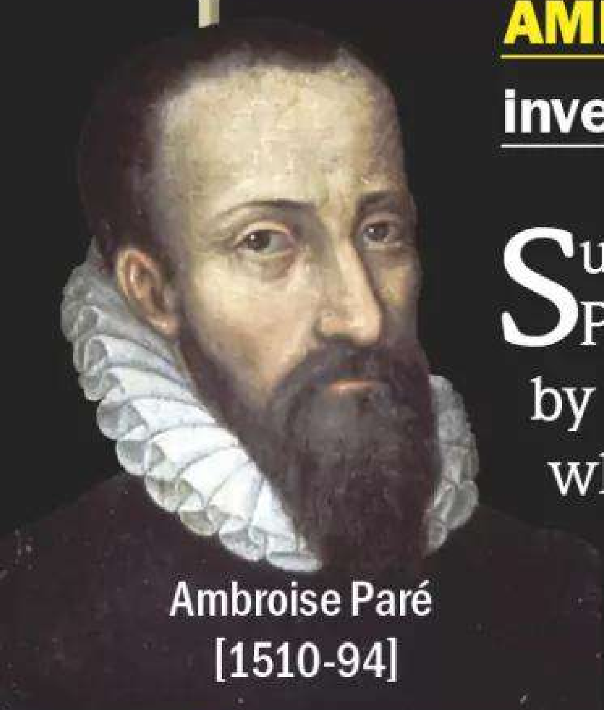
In Asia, the great physician of the Indus culture, Sushruta, practised a wide range of surgical procedures and was a renowned expert in **cosmetic surgery** – especially nasal reconstructions. He wrote the first surgical manual in history called *Sushruta Samhita*.

500 BC

Chinese doctor Bian Qiao reportedly experimented with **heart transplantation**. In one case, he swapped the hearts of two volunteer soldiers. It's not known if the men survived.

Ligated arteries saved soldiers from death

AMBROISE PARÉ | Surrounded by the horrors of war, a young field surgeon invented a surgical method that saved countless lives: ligating arteries.



Ambroise Paré [1510-94]

ART ARCHIVE

Surgeon Ambroise Paré was greeted by a horrific sight when he arrived on the battlefield near Turin. Large groups of wounded soldiers lay bleeding among those who were already dead. Some were moaning for help, others screaming. Paré immediately realised that he could only help a few of them.

The year was 1537 and the 27-year-old man was serving as a field surgeon in the French army. His first encounter with war was on a section of the front line during the siege of Turin. King Francis I had once again gone to war against the Holy Roman Empire, and once again the fighting was brutal.

The bloody battles were due in no small part to the fact that the musket had now become a standard weapon in European armies. Previously, soldiers' injuries had mainly consisted of clean stab wounds from knives and swords, but a musket ball had a different, brutal effect. It pulled fabric and gunpowder into the wound, wreaking havoc on muscle and tissue, and ripping through blood vessels. Often the bullet was only stopped when it shattered a bone. In most cases, severe haemorrhaging followed.

Paré was a typical 16th-century surgeon. Weapons had become ever more deadly, but surgery had failed to keep pace. The profession was still considered a craft, and like most, he'd no formal training. Paré had previously worked as a barber surgeon in a Parisian hospital, where well-trained doctors provided the diagnosis, while surgeons were called in when a patient needed cutting open. Paré therefore derived all his knowledge from practical work.

Iron stopped bleeding

Prior to his arrival in Turin, Paré had never performed an amputation, but within the first few days, he was already sawing off soldiers' arms and legs. He tried to stop the heavy bleeding by pressing red-hot iron against the wound after each procedure. If the soldiers had not already bled to death, this shock treatment often killed them. Similarly, bleeding from gunshot wounds was only stopped by applying boiling oil to the wound.

Paré despaired. Soldiers bled to death in front of him as he watched helplessly. When the fighting subsided at the end of the day, he sat in his tent trying to find a more humane treatment.

Paré's solution was surprisingly simple. It consisted of squeezing a blood vessel with a pair of tweezers. Although several smaller blood vessels continued to pump blood, bleeding was reduced, and the surgeon gained precious time during an amputation. Later, Paré also realised that he could tie off the blood vessel with silk thread and effectively stop the bleeding. He left the thread in place, allowing the dried-up piece of blood vessel to fall off while the wound healed.

A difficult solution

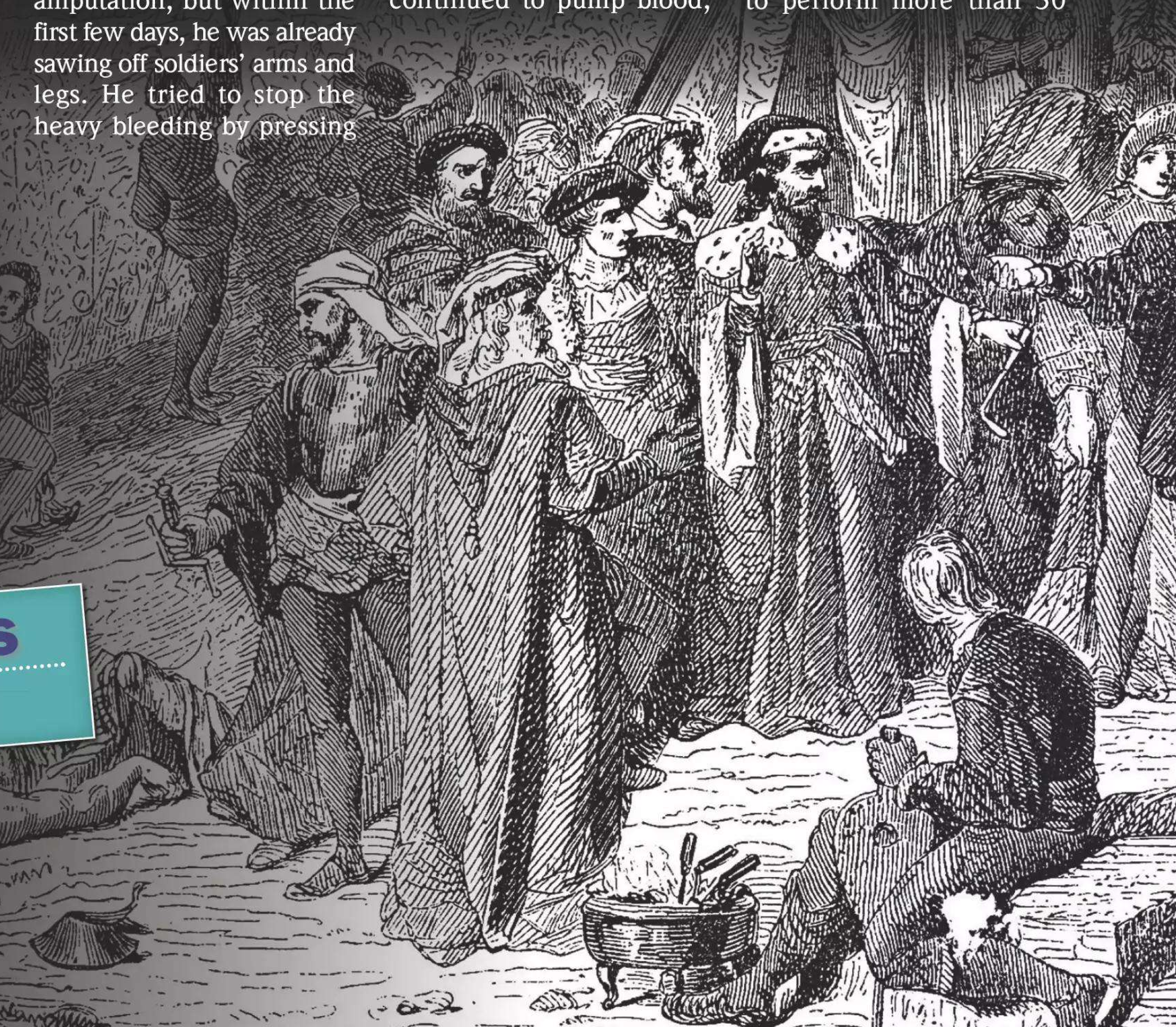
However, the method proved difficult to implement. To completely stop the bleeding in a thigh, for example, he had to perform more than 50

POLFOTO/ULLSTEIN BILD

Ambroise Paré's books demonstrate many methods for treating wounds.

BLOOD LOSS

Torino, 1537



BEFORE PARÉ *Córdoba, around AD 1000*

All Europe studied Muslim doctor

During the Middle Ages, Moorish culture in Spain led Europe in many ways, and the surgeon Abu al-Qasim al-Zahrawi (AD 936-1018) was the foremost practitioner of medicine of his time.

As early as 963, he was the first to learn about ectopic pregnancy and discover that haemophilia is hereditary. In addition, al-Zahrawi knew dental surgery, set shoulders and developed the use of catgut (gut string) for stitching inside the body – a method that's still used today.

However, the Muslim doctor's greatest claim to fame was his ability to stop excessive bleeding. He ligated blood vessels and stopped bleeding with red-hot iron, which was painful but effective.

Al-Zahrawi's books were studied throughout Europe and in 1453, Italian

MARY EVANS

Al-Qasim believed the sick healed quicker if they had a good relationship with their doctor.

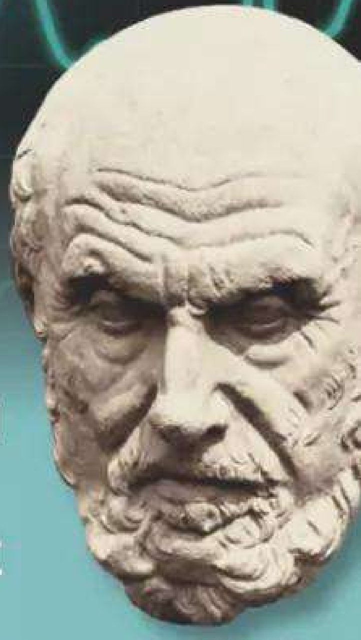
surgeon Pietro Argallata described him as "without doubt the chief of all surgeons". Nevertheless, al-Zahrawi was forgotten when the Moors were expelled from Spain in 1492. For the same reason, Ambroise Paré was apparently unaware of al-Zahrawi when he reinvented the ligation of arteries on a battlefield near Turin in 1537.

tourniquets. In a field hospital, no more than 10 tourniquets could be performed before the patient bled to death. And applying forceps to a leaking blood vessel while the blood pumped out under high pressure also proved difficult.

It wasn't until physician Jean Louis Petit designed the first modern tourniquet in 1718 that it became possible to stop heavy bleeding in difficult conditions. However, Paré's inventions elevated him from unknown field surgeon to one of France's most recognised practitioners in the field.

By tying off blood vessels, Paré was able to stop bleeding and gain enough time to complete an amputation.

SCANPIX/GRANGER



SCIENCE & SOCIETY

C. 400 BC

The Greek Hippocrates (c. 460-370 BC) had his own medical school on the island of Kos, where he – or a student – formulated the Hippocratic Oath, **the ethical basis** of modern medicine. Hippocrates wrote 53 books and formulated the idea that disease has a "natural cause". He also made it common practice to keep patients under observation before an operation.

3rd century BC

Eristratus (304-250 BC), a physician at the Greek court of King Seleucus I in Syria, was the first to identify **the heart as a pump** and not the centre of emotions as his contemporaries assumed. He also recognised the difference between veins and arteries, and prescribed bloodletting as a treatment.

AD 1180

In his great textbook *Practica Chirurgiae*, Italian physician Rogerius recommended using egg whites to treat open wounds. Rogerius also suggested that at least a few years of **study and training** were needed before anyone should be allowed to practise surgery. However, the principle did not become commonplace until late in the 13th century.

15th century

During the Renaissance, surgeons used special calendars that recorded the best times to perform **bloodletting** in relation to the phases of the moon. For example, a calendar from Vienna for 1462 states that the Wednesday after the feast of St Bartholomew was ideal – but only at midnight.

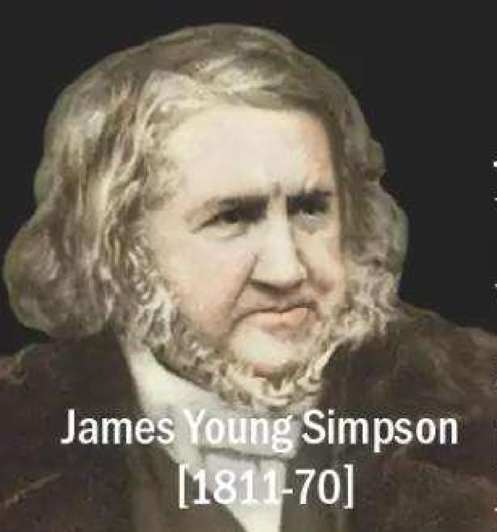
BRIDGEMAN

Elsewhere, Aztecs in modern-day Mexico could cure compound bone fractures with **bone setting**. If the bone was broken, they would insert a branch into the cavity containing the marrow to hold it together. Modern science only developed a similar technique in the 20th century.

ANAESTHESIA
Edinburgh, 1847

Chloroform killed the pain

JAMES YOUNG SIMPSON | Desperate to find an effective anaesthetic, Simpson consumed a wide range of chemicals – until he came across chloroform.


James Young Simpson [1811-70]

MARY EVANS

Aged 16, Scottish obstetrician James Young Simpson was witness to an amputation in London. It had been performed without anaesthetic and with great suffering to the patient – who died from blood loss. The horrific experience never left Simpson. He now worked at the University Hospital in Edinburgh, where he still believed his main concern was his patients' pain.

In the mid-1840s, childbirth was still a deadly affair. A few years earlier, the use of ether made it possible to relieve the pain, but ether was highly flammable and fumes near hospital gas lamps posed an acute explosion hazard. Furthermore, incorrect dosing could cause instant death, and no one knew if ether harmed newborns. Simpson was determined to seek out a better alternative.


SCIENCE MUSEUM/SSPL

Chloroform's popularity led to the invention of many anaesthetic devices – this is from 1862.

Simpson experimented

Initially, Simpson experimented on himself. He mixed any chemicals he could get his hands on and drank or inhaled them.

One day in 1847, he found a clear liquid in a Liverpool chemist's shop. The bottle was labelled 'chloroform' and the pharmacist told him that the contents had been invented 16 years earlier for asthma. In his home, Simpson took a deep breath from the bottle and went out like a light.

At a dinner party a few days later, Simpson let his guests try out the new drug. The atmosphere immediately became light-hearted, and the conversation relaxed and hazy. Several people lay down or collapsed on the floor.

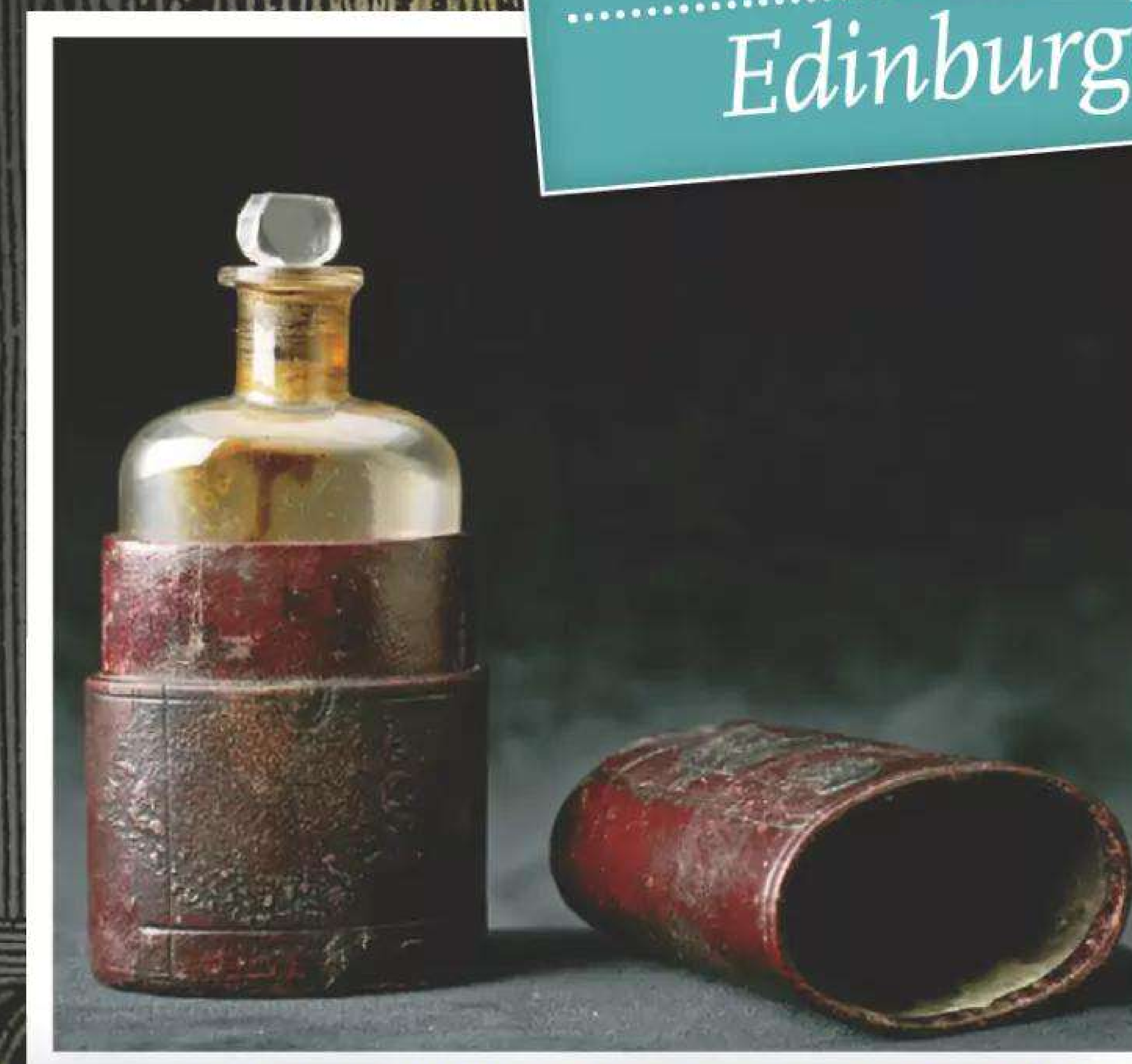
Simpson was convinced that he had finally found the drug that would revolutionise surgery. Chloroform was far more effective than ether. The anaesthesia was deeper and easier to control. "A little of the liquid diffused upon [a] sponge, or a pocket handkerchief ... held over the mouth and nostrils, as to be fully inhaled, generally suffices in a about a minute or two to produce the desired effect," Simpson wrote.

Chloroform won the day

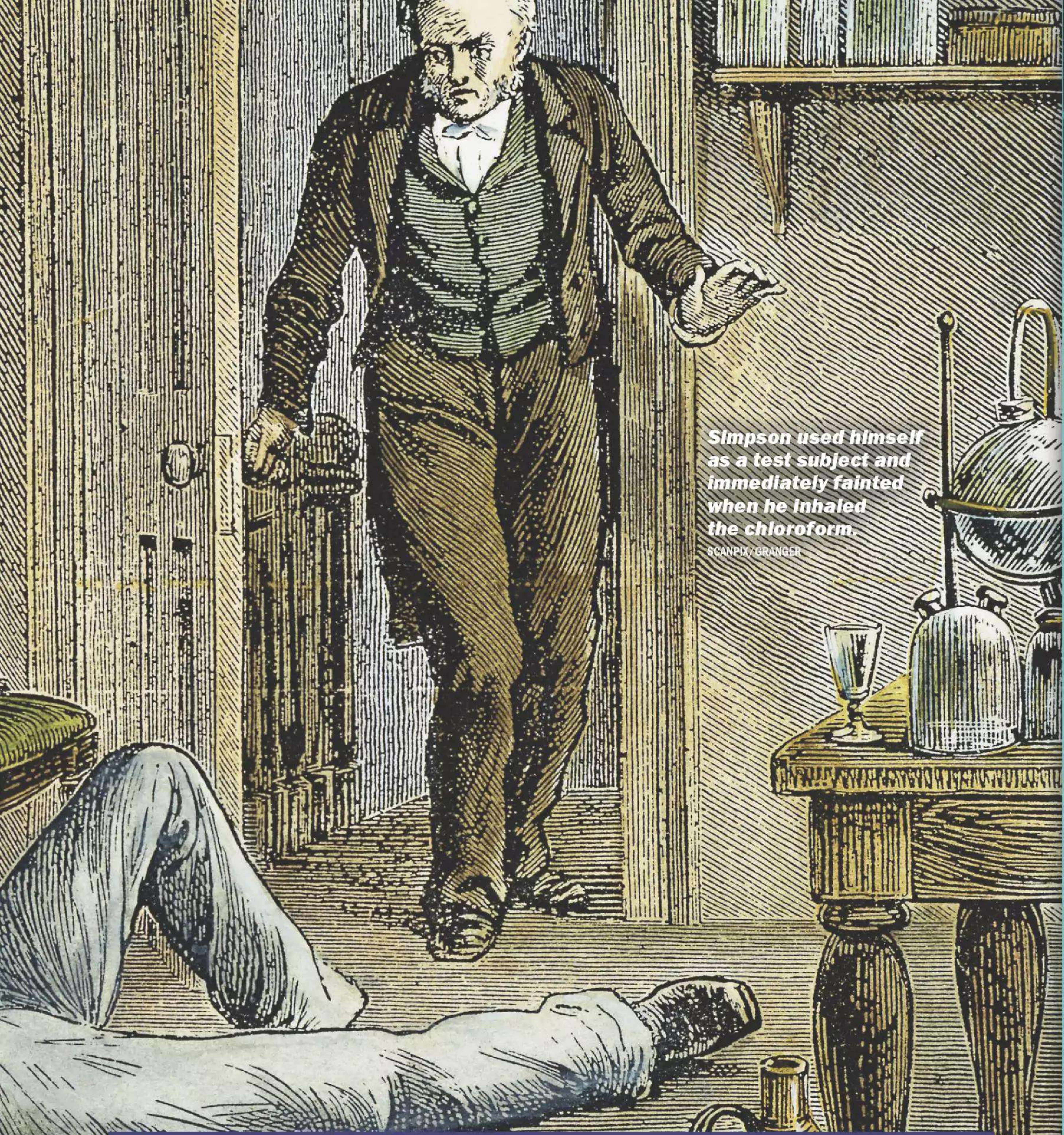
The obstetrician began a tireless campaign to publicise chloroform and soon doctors across Europe were embracing the drug and experimenting eagerly to improve its use. Public scepticism was still high, but this disappeared when Queen Victoria used chloroform during the birth of Prince Leopold in 1853.

Unfortunately, chloroform also began to prove deadly. As the drug became popular, the death toll grew and, to everyone's surprise, fatalities were mostly young, strong people. Simpson couldn't solve the mystery, but his colleague John Snow discovered that chloroform affected breathing and the heart – and that there was a fine line between unconsciousness and death. A third of a teaspoon of chloroform was enough to anaesthetise a patient, while half a teaspoon was fatal. Young people needed a larger dose than older people and therefore came closer to the dangerous limit.

Despite this, Simpson was widely lauded. He was knighted and given a coat of arms with the inscription *Victo Dolore* ("Victory over pain"). And when he died in 1870, 30,000 people followed his coffin through the streets of Edinburgh.


BRIDGEMAN

Simpson liked to use chloroform himself. Above is his private bottle.



Simpson used himself as a test subject and immediately fainted when he inhaled the chloroform.

SCANPIX/GRANGER

BEFORE SIMPSON *Qiao, 2nd century AD*

Doctor burned his papers

Hua Tuo (died in AD 208) stands as one of the great doctors in Chinese history. He grew up in the city of Qiao, known for its healing herbs. Hua Tuo eagerly studied the local plants and soon gained a reputation as a master of herbal medicine. He was particularly interested in the anaesthetic effects of plants and began experimenting with surgery under anaesthesia.

In one example, according to Chinese sources, he operated on a man's abdomen after giving him a dose of homemade anaesthetic consisting of plant extracts – including cannabis – mixed with alcohol.

In time, Hua Tuo became so famous that Emperor Cao Cao summoned him to treat his headaches. However, when the doctor eventually travelled home to care for his sick wife, the emperor ordered him executed and his medical notes confiscated. Hua Tuo begged his guard to hide his records, but the guard refused for fear of Cao Cao. As his final act, Hua Tuo burned all his recipes for potions so that the emperor wouldn't get hold of them.

SCIENCE PHOTO LIBRARY

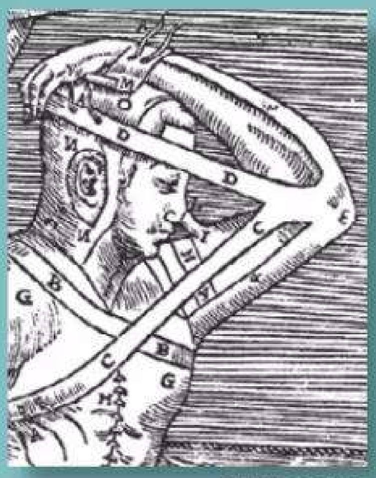
Hua Tuo was known for his herbal anaesthetic.

1590

The German-Dutch optician Hans Lippershey constructed **the first microscope**. But it wasn't until 1625 that the astronomer Galileo Galilei built the model that became the archetype for the modern optical microscope. Galileo's microscope was a by-product of working with a telescope.

1597

Surgeon Gasparo Tagliacozzi found a way to **sustain blood flow** in transplanted skin. He rebuilt the nose of a syphilis patient and attached it to a flap of skin from the arm. After two weeks, he separated the two body parts and the nose healed with healthy skin.



UNIVERSITY OF KANSAS

1765

James Spence made a name for himself by **transplanting teeth** in London. In 1765, he extracted the front teeth from a poor woman and placed them in the mouth of a young, wealthy woman for a few coins. Shortly afterwards, the donor was found to have syphilis, and a few months after the transplant, the patient died.

1818

Briton James Blundell performed the first successful **blood transfusion** using human blood. During a complicated labour, a patient lost so much blood that Blundell had to transfuse blood from the woman's husband.

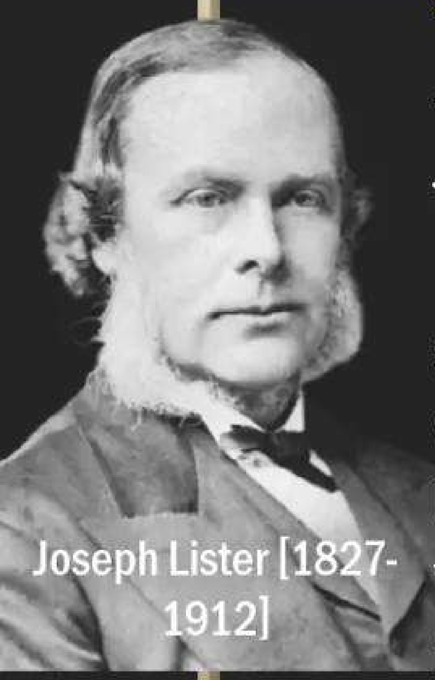
ULLSTEIN BILD

1853

Scottish doctor Alexander Wood invented **the hypodermic syringe**. His wife adopted the invention and became addicted to morphine – she later died of an overdose. The tubular metal needle had been invented nine years earlier by Francis Rynd, who injected tranquillisers into his patients through their veins.

"Little beasts" in the air couldn't possibly kill a man!

JOSEPH LISTER | Scores of surgical patients died from infections until an English surgeon realised that bacteria could be fought chemically.



Joseph Lister [1827-1912]

SCIENCE PHOTO LIBRARY

When a patient was hospitalised with an open leg fracture, doctors in the 1860s knew that the wound would become infected in a matter of days. Gangrene would soon follow, and amputation was the only chance to save the patient's life. Even though surgeons could control bleeding and use anaesthesia, infections still pushed the mortality rate up to around 50 per cent.

Joseph Lister pondered the problem. The professor of surgery at Glasgow's University Hospital had apprenticed with the foremost surgeons of the time in London. The most skilful could amputate a leg in just 25 seconds, yet patients often died from infection. Lister was determined to find the cause of these mysterious inflammations.

At the Glasgow hospital, some believed the infections were caused by the polluted industrial air. Others that the hospital was built on a graveyard for cholera victims. Lister had his own theory.

As a young man, he had cut into frogs and examined their infected wounds with his father's microscope. He had observed a myriad of microorganisms, but he didn't understand where they came from – until he heard about Louis Pasteur.

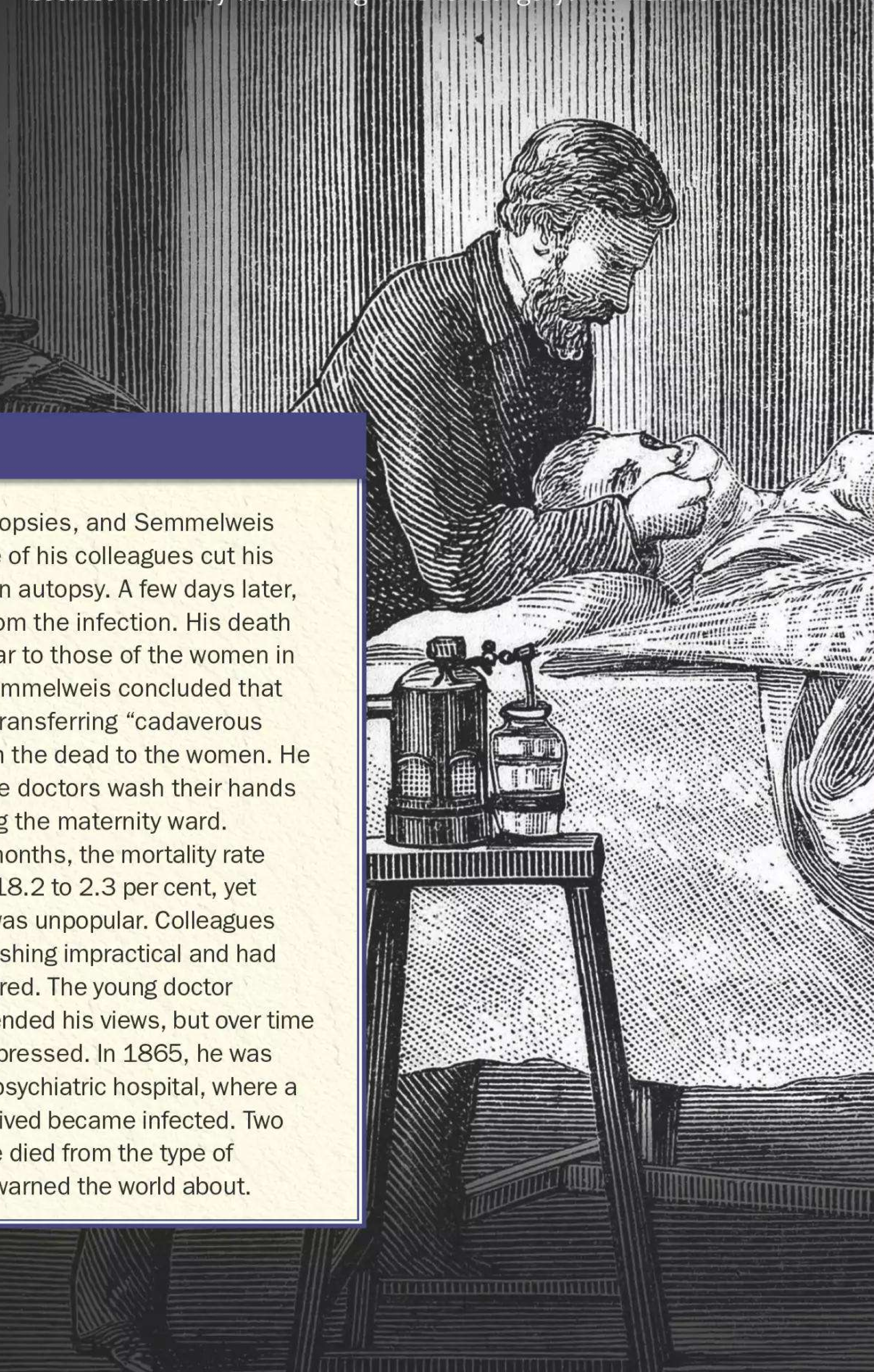
The French biologist had just discovered that sterile material in a bottle remained sterile even if the bottle was simply closed with cotton wool. Only air and nothing else could pass through the cotton wool, and Pasteur had proved that it was not the air, but microorganisms in the air that affected the material in the bottle.

Phenol was the solution

Lister concluded that microorganisms were also killing his patients. This also explained why the death rate had increased since surgeons started using anaesthesia – because now they were taking their time during surgery, they were exposing patients to microorganisms for longer. Pasteur had boiled his samples, and that method was out of the question, so any solution had to be chemical.

Joseph Lister found the answer in the city of Carlisle, where the city council used the chemical phenol – carbolic acid – in a new wastewater treatment plant. The chemical eliminated all odours and Lister concluded that it must be because phenol killed microorganisms.

The surgeon didn't waste time with lab experiments, but put his idea into practice in August 1865, when an 11-year-old boy was brought in for surgery. He had been



BEFORE LISTER *Vienna, 1847*

Hand washing saved lives

At the hospital in Vienna, one maternity ward was run by midwives, while male doctors took care of the other. A study from 1846 showed that doctors lost about four times more patients than midwives.

Ignaz Semmelweis (1818-65), a young doctor in the maternity ward, found the explanation. In between deliveries, doctors performed autopsies, and Semmelweis witnessed one of his colleagues cut his finger during an autopsy. A few days later, he had died from the infection. His death was very similar to those of the women in labour, and Semmelweis concluded that doctors were transferring "cadaverous particles" from the dead to the women. He therefore made doctors wash their hands before entering the maternity ward.

In just two months, the mortality rate dropped from 18.2 to 2.3 per cent, yet Semmelweis was unpopular. Colleagues found hand washing impractical and had Semmelweis fired. The young doctor vigorously defended his views, but over time he became depressed. In 1865, he was admitted to a psychiatric hospital, where a wound he received became infected. Two weeks later, he died from the type of infection he'd warned the world about.

POLFOTO/CORBIS

Semmelweis had doctors wash their hands in chlorine with a chemical mixture.

INFECTION

Glasgow, 1865

run over by a carriage, which had crushed one of his shins and left a large open wound.

No tell-tale stench

Lister cleaned out the wound with carbolic acid, then covered it with a lint dressing dipped in phenol before wrapping the leg in tinfoil to stop the phenol evaporating. After adding splints, the boy was seen again four days later. Lister expected a rotten odour when he renewed the dressing, but the wound was free of infection. Six weeks later, the boy walked home on his own feet – and Lister had invented antiseptic surgery.

"A most encouraging result," he noted, publishing his results the following year. By then, he'd performed 11 surgeries and lost just one patient – to unrelated issues.

Despite its success, the new method met with resistance. Lister developed a device that atomised phenol so that the entire operation took place in a spray of carbolic – working conditions that many surgeons refused to accept. For example, a doctor at Bellevue Hospital in New York had to operate in a tent outside because the rest of the hospital staff would not put up with the smell.

Older colleagues dismissed Lister as a liar. It couldn't be true that "little beasts" from Lister's imagination could kill a grown man, they said.

Gradually, however, it was accepted. Little by little, the wooden operating tables were replaced with steel, and the blood-stained floors were covered with linoleum. The surgeons replaced their old coats with freshly laundered scrubs and donned rubber gloves. And with that, the final step towards transforming surgery into a modern science had been taken.

With Joseph Lister's discovery, the death rate after amputations was reduced from as much as 50 to 15 per cent.

WELLCOME LIBRARY LONDON

BRIDGEMAN

Operating theatres were sterilised by a device that sprayed phenol.

SHUTTERSTOCK

BRIDGEMAN

1895

While experimenting with electricity, German physicist Wilhelm C Röntgen discovered an unknown form of radiation, which he named **X-rays**. Röntgen realised the medical potential of the rays when they left a photographic impression of his wife's hand on which her bones were visible.

1928

While experimenting with bacteria, biologist Alexander Fleming discovered **penicillin**. By accident, one of his dishes containing staphylococcal bacteria became contaminated with fungus and Fleming observed that the bacteria did not grow near the fungal colony. His studies showed that the Penicillium fungus could fight several pathogenic bacteria.

1930

In 1930, Dane Einar Wegener underwent five operations to **surgically transform him into a woman**. The first operations removed Wegener's testicles and penis, and implanted an ovary – however, it was removed again due to complications. During the last operation, Wegener had a uterus inserted to make her fertile. Three months later, she died.

1967

South African Christiaan Barnard performed the first successful **heart transplant**. The heart came from a brain-dead young woman and was implanted in a 54-year-old man. The patient lived 18 days after the procedure before dying of pneumonia.

1998

In Leipzig, surgeon Friedrich-Wilhelh Mohr performed the first **robot-assisted bypass surgery**. Each of the robot's four arms could handle surgical tools, rotate 360° and were far more precise than human hands.

WELLCOME IMAGES

Draper discovered a world of tiny monsters

In the 1670s, Dutch cloth merchant Anton van Leeuwenhoek turned the scientific world view upside down. Using a self-built microscope, he managed to see nature's tiniest creatures.

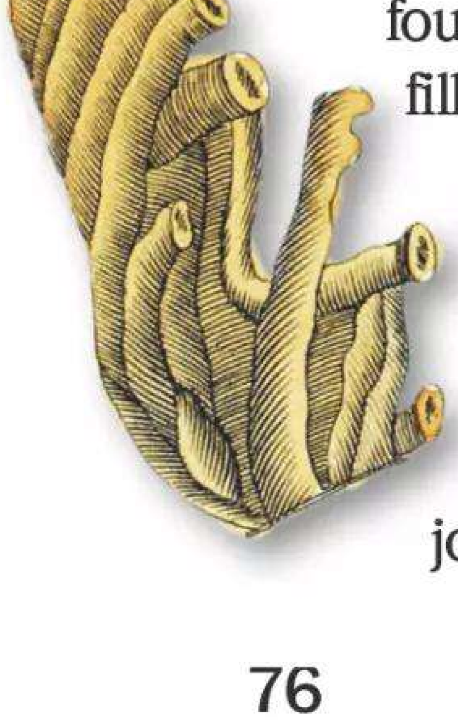
DELFT/1676

The latter half of the 17th century was the Dutch Republic's golden age. The small seafaring nation controlled most trade across the world's oceans, and in its cities – including Delft – art and science flourished like never before.

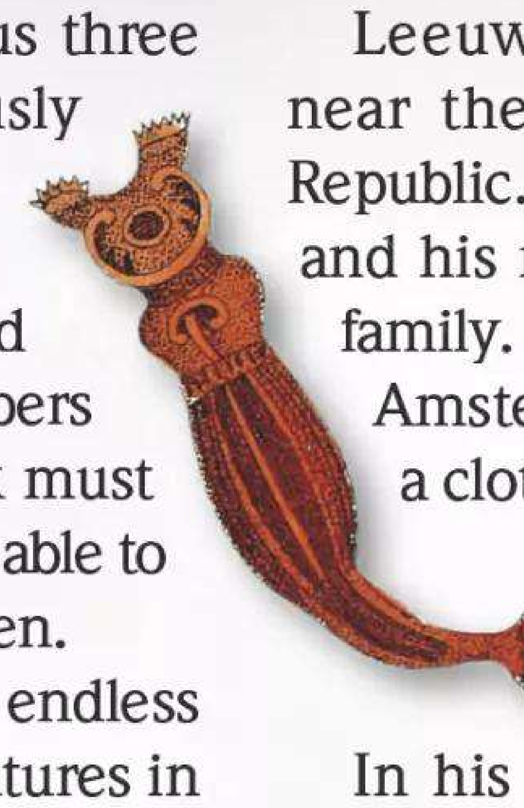
BY KASPER NIELSEN

On 9th October 1676, Britain's Royal Society of Science received a letter from a Dutch cloth merchant who claimed – with a homemade microscope – to have discovered myriads of tiny animals in a drop of rainwater:

"Ten hundred thousand of these living creatures could scarce equal the bulk of a course grain of sand," he wrote.



The letter writer's name was Anton van Leeuwenhoek, and his claim to have found a previously unknown world filled with infinite numbers of tiny, monstrous-looking creatures caused consternation at the Royal Society, publisher of *Philosophical Transactions*, the most prestigious scientific journal of its time. Despite some scepticism among the journal's associated experts, the Society had published several articles from the otherwise unknown Leeuwenhoek over the previous three years. In them, he meticulously described everything from the number of joints in a louse's antennae to the size of red blood cells. But more and more members began suggesting Leeuwenhoek must be a fraud when he claimed to be able to see what no one else had ever seen.



His latest missive, describing endless quantities of tiny grotesque creatures in the tiniest drops of water had the Royal Society up in arms. Such an outrageous claim couldn't possibly be published.

From draper to lens expert

The first 40 years of Leeuwenhoek's life gave no indication that he would turn the scientific world view upside down and shake Europe's most prestigious academic society to its foundations.

Leeuwenhoek was born in 1632 near the city of Delft in the Dutch Republic. His father was a basket maker and his mother came from a brewing family. As a young man, he moved to Amsterdam and was apprenticed to a cloth merchant. After a few years, Leeuwenhoek returned to Delft where he opened his own business.

In his daily work handling textiles, Leeuwenhoek used a magnifying glass to examine the fabric's quality. This sparked his interest in making magnifying glasses. The cloth merchant was further inspired by the leading expert in microscopy of the time, Englishman Robert Hooke, who'd discovered with his double-lens ▶

The 0.2 to 5-mm-long daphnia – also known as the water flea – could be seen with the naked eye. However, Leeuwenhoek discovered that even smaller organisms lived on the flea's body.

POLFOTO/CORBIS & HERITAGE IMAGES

150 years ahead of time

With his simple single-lens microscope, Anton van Leeuwenhoek was able to see and draw organisms completely unknown at the time. Some of the single- and multicellular organisms he discovered were only closely studied again in the 19th century. He was the first to describe *Philodina roseola* – a microscopic animal that lives in fresh water.

Leeuwenhoek drew the 0.1-0.5 mm-long* Philodina roseola *in minute detail.

DOUGLAS ANDERSON & WIM VAN EGMOND

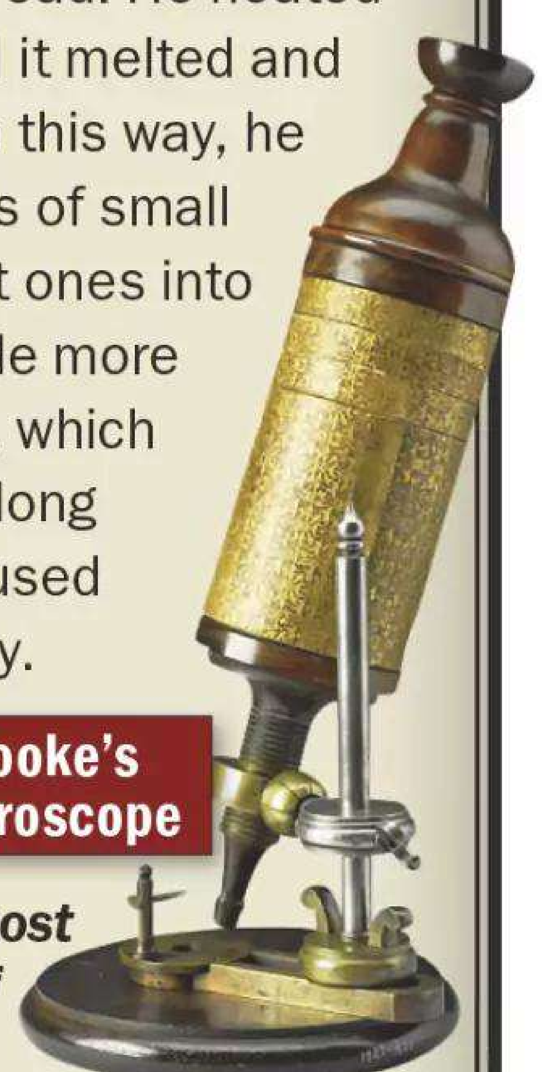
SCANPIX/GRANGER & SSPL

Simple microscope broke all records

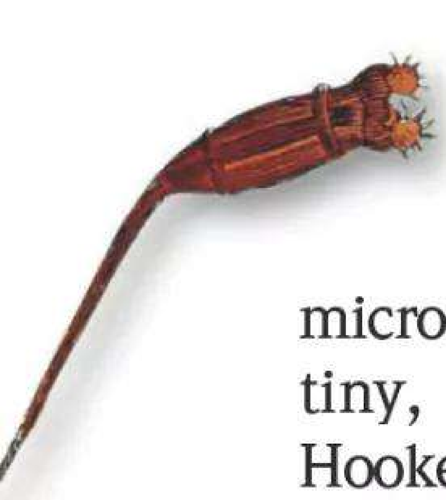
Leeuwenhoek mass-produced hundreds of lenses specifically for the objects he wanted to study.

The best of Anton van Leeuwenhoek's lenses could magnify up to 300 times. Even the leading microscopic expert of the time, Robert Hooke, had to yield to Leeuwenhoek. But how he was able to outdo everyone in precision lens-grinding remains a mystery.

Some scholars believe he used a special technique where he pulled raw glass into a hair-thin thread. He heated the end of the wire until it melted and formed a round drop. In this way, he could produce hundreds of small drops, grinding the best ones into lenses. In total, he made more than 400 microscopes, which he packed into boxes along with the samples he'd used for each individual study.



Robert Hooke had the most advanced microscope of the 17th century, but it couldn't beat Leeuwenhoek's.



microscope that plant tissue consisted of tiny, finely organised "cells", which Hooke named after the solitary monastic rooms inhabited by monks.

At the time, scientists were only just beginning to explore the microscopic world – largely because a microscope's tiny lenses were much harder to make than, for example, the saucer-sized lenses of a telescope. The Venetian glass lenses of the time were ground and polished with increasingly finer material until they had the right shape – a time-consuming job that could only be done by a few experts in Europe.

But that didn't stop the energetic Leeuwenhoek, who in his spare time began grinding small glass lenses and clamping them between two metal plates to create a simple single-lens microscope he could use.

Amateur became leading expert

With his handheld microscope, Leeuwenhoek now began to study the smallest details of plants and animals. For hours, he stared into the lens, often with his head turned at painful angles to allow as much light as possible to shine on his samples.

Some lenses didn't have the right optical properties for certain samples, and other lenses magnified too much or too little, so the draper had to repeatedly disassemble his equipment to try new lenses. Little by little, microscopic details were revealed, which Leeuwenhoek then spent weeks and months piecing together into a precise image.

Soon he had refined both his lenses and his powers of observation to such an extent that he was even able to detect errors in Hooke's observations. In 1673, he dared to send his first letter to the Royal Society. In polite terms, he pointed out that Robert Hooke's understanding of the mechanics of a bee sting must be wrong. Moreover, according to Leeuwenhoek, it was clear that a louse's antennae consisted of five joints and not four, as Hooke had written.

The clothier's letter put the Royal Society's panel of experts on the back foot. Several were sceptical of Leeuwenhoek's postulations, but the Royal Society's first secretary and editor-in-chief, Henry Oldenburg, decided to print the article.

Leeuwenhoek's secret

The Royal Society's decision motivated Leeuwenhoek to send Oldenburg dozens of letters over the following months and years, requesting close-up studies of everything from bones and saliva to semen and blood. However, it wasn't the hope of recognition that drove the almost self-effacing cloth merchant, but his immense curiosity:

Milestones in microscopy

Both the ancient Egyptians and the Romans knew about magnifying glasses and optical lenses. But the microscope didn't arrive until the 1600s.

1608
German-Dutch spectacle maker Hans Lippershey invents a simple microscope.

1609
Galileo Galilei develops a microscope with convex and concave lenses.

"Most students go there to make money out of science, or to get a reputation in the learned world. But in lens grinding, and discovering things hidden from our sight, these count for nought," Leeuwenhoek wrote.

Each submission to the Society was accompanied by detailed measurements of the material Leeuwenhoek had studied. In the 17th century, there were no units of measurement for microscopic sizes. Therefore, he invented his own unit of measurement, comparing an organism to a grain of sand or a strand of hair from a wig, for example.

"The red Globules of the Blood I reckon to be 2,500 times smaller than a grain of sand," he wrote after studying red blood cells.

According to Leeuwenhoek's calculations, the red blood cells had a diameter equivalent to 0.0085 millimetres, or 8.5 micrometres (µm). This was a mere 1.3 µm away from the approximately 7.2 µm that scientists today estimate their diameter to be.

Despite several requests from the Society, Leeuwenhoek refused to reveal how he achieved his remarkable results: "My method ... I do not impart to others ... That I keep for myself alone."

In reality, the Dutchman's technique was not very sophisticated. Compared to the double-lens microscope that Robert Hooke had customised in gold and leather, Leeuwenhoek's equipment was more akin to a magnifying glass. But his lenses were unrivalled, and he possessed almost inhuman powers of concentration and observation: "On the close inspection of three or four drops, I may indeed expend so much labour that the sweat breaks out on me," he confessed in one of his letters.

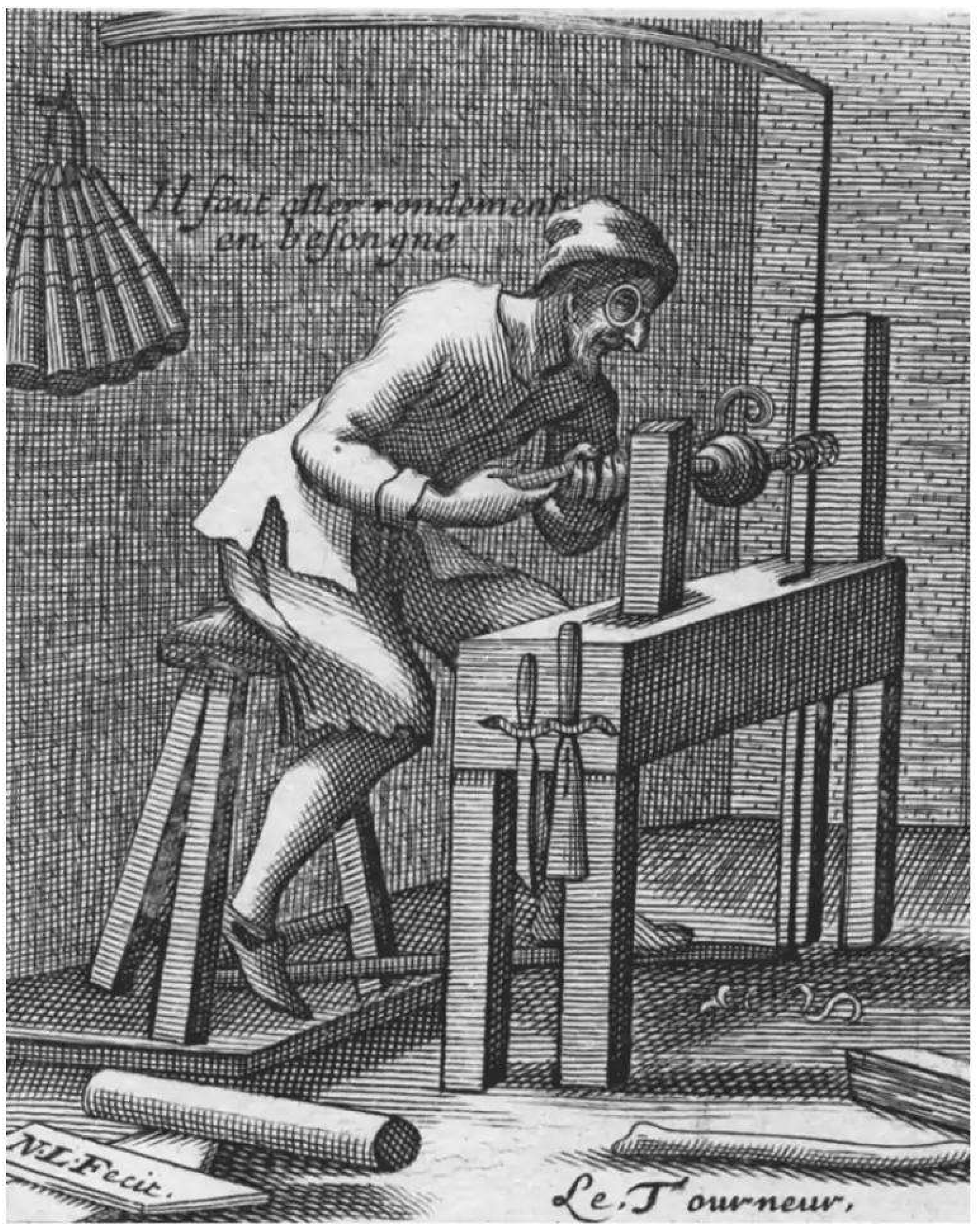
Living creatures in rainwater

The Royal Society's publications of Leeuwenhoek's observations ended abruptly, however, when the Dutchman sent his observations describing millions of tiny organisms in even the smallest water droplets in 1676.

The Royal Society's rejection only prompted Leeuwenhoek to intensify his close study of the organisms he had seen.

"Among all the marvels that I have discovered in nature, [this is] the most marvellous of all; and I must say, for my part, that no more pleasant sight has ever yet come before my eyes than this of so many thousands of living creatures in one small drop of water," he wrote of the organisms, which for lack of a better term he called "animalcules" – small animals.

From the descriptions, scientists now know that Leeuwenhoek was the first to see the secret world of bacteria and single-celled organisms.



SCANPIX/AKG-IMAGES

Leeuwenhoek used a large lathe to grind his glass lenses. It was powered by a foot pedal and a rod clamped to the ceiling.

Royal Society relented

Despite the rejection of Leeuwenhoek's observations, after several months of reflection, the Royal Society decided to commission a recognised scientist to verify the Dutchman's claim. The task fell to Robert Hooke, who in November 1677 – more than a year after Leeuwenhoek's letter – set about repeating Leeuwenhoek's experiment in front of selected members of the Royal Society.

Only after two weeks of experiments with hundreds of water samples, lenses and alternative setups did he finally manage to spot the microorganisms Leeuwenhoek had seen: "It seems very wonderful that there should be such an infinite number of animals in so imperceptible quantity of matter," Hooke wrote to Leeuwenhoek, pointing out that no less than King Charles II, patron of the Royal Society, had seen the tiny creatures and mentioned Leeuwenhoek by name.

In 1680, the Dutch cloth merchant was made a life member of the Royal Society – the highest academic honour anyone could achieve in the late 17th century. The energetic Dutchman continued to study his little "animalcules" until his death in 1723 at the age of 90.

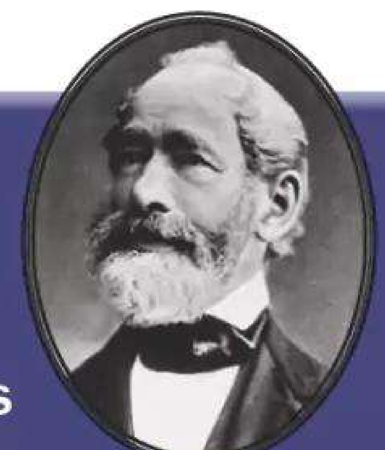
By then, he had long since become famous in most of Europe. However, recognition never went to his head: "My work, which I've done for a long time, was not pursued in order to gain the praise I now enjoy, but chiefly from a craving after knowledge, which I notice resides in me more than in most other men," he wrote seven years before his death.

In all, the draper from Delft published over 100 articles and is now known as the "Father of Microbiology".

1665 Robert Hooke publishes the illustrated book *Micrographi.*

1675 Anton van Leeuwenhoek discovers bacteria and single-celled organisms.

1886 Inventor Carl Zeiss develops a new type of glass that facilitates distortion-free lenses.



1931 Physicist Ernst Ruska develops the electron microscope.

1982 Heinrich Rohrer and Gerd Binnig invent the STM microscope to view single atoms.

SCANPIX/GRANGER & POLFOTO/ULLSTEIN & ALL OVER PRESS/SSPL

The bullet-like shape of the rabies virus makes it easily recognisable, but in Louis Pasteur's time, it was an invisible enemy. Scientists' microscopes weren't yet powerful enough.

POLFOTO & SCANPIX

FRANCE/1865

Doctors stated that something as small as a bacterium couldn't possibly kill a human being. French chemist Louis Pasteur wasn't so sure. He saw microorganisms as a possible cause of disease.

Virus hunter was father of medicine

Chemist Louis Pasteur *became a hero 140 years ago when he discovered a vaccine against the deadly disease rabies. But even before that, his research laid the most important foundation for modern medicine: hygiene.*

BY KLAUS LARSEN

No rabid dog should be approached – let alone poked with a stick, as nine-year-old Joseph Meister did one July day in 1885. The dog attacked, and the boy was mauled. His mother knew that he had probably contracted rabies – so would be doomed to a horrible death. However, the despairing mother saw a glimmer of hope: rumours of the famous chemist Louis Pasteur's vaccine trials had also reached the Meister family's small village in Alsace.

Madame Meister travelled with her savaged son to the town of Arbois, where Pasteur had his laboratory, and begged him to save the boy.

The French press portrayed Pasteur as a saviour when he developed a vaccine against rabies.

SCANPIX

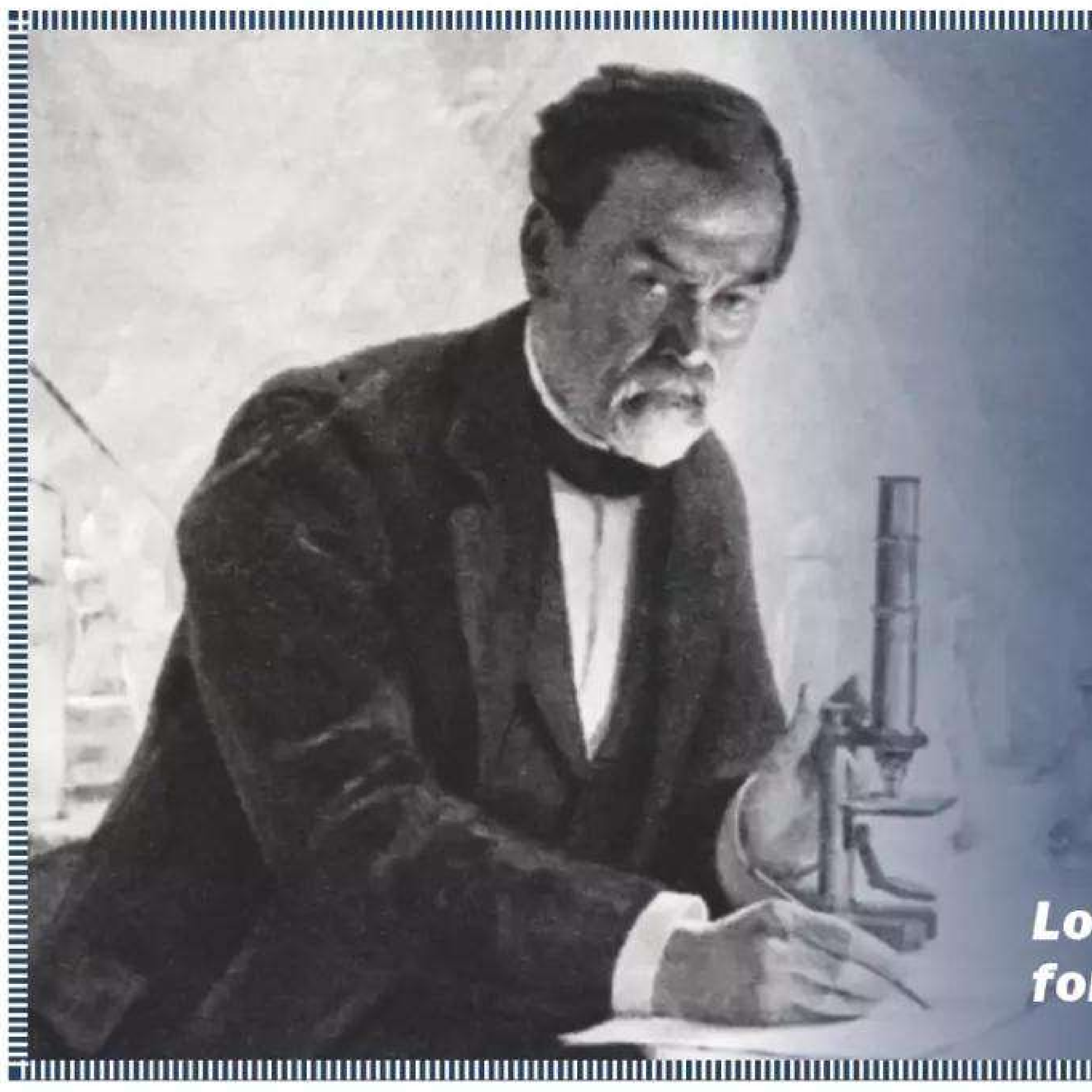
Pasteur broke with tradition

In 1885, the 63-year-old Pasteur had long since become world famous. When 2,000 doctors from all over the world met at a congress in Copenhagen the year before, he'd been treated like a superstar. The period was one characterised by enthusiasm for scientific breakthroughs, which followed one after the other at an unprecedented pace. This was especially true in the field of medicine, and renowned Danish writer Georg Brandes noted that doctors were the literary heroes of the new age.

Pasteur was the epitome of such a modern hero and was celebrated because his work had finally rendered the understanding of disease as scientific. And he wasn't even a doctor himself – he was a chemist specialising in crystals.

For thousands of years, superstition and speculative theories had characterised medicine. Its practitioners believed that infectious diseases and epidemics were caused by vapours from stagnant water and moist soil. When cholera struck, doctors responded with sweat cures, bloodletting, herbal decoctions, applying mustard to the soles of the feet and rubbing with rags.

The list of follies was endless: syphilis patients were given mercury to 'purge' them, but the infection remained. People died of whooping cough, diphtheria and common strep ▶



Tanner's son had a great career

Louis Pasteur was born in a village in eastern France in 1822. His father ran a small tannery that provided a modest living. No one would have guessed that Louis would have an academic career, but at school he proved to be exceptionally diligent and gifted. A teacher persuaded Pasteur senior to allow his son to attend the secondary school in Arbois, rather than apprentice him to the tannery himself.

From Arbois, he moved on to study in Paris. Pasteur enrolled at the elite École Normale Supérieure, where he earned a doctorate in chemistry in 1847. In 1849, he was appointed professor of chemistry at the University of Strasbourg and married his rector's daughter, Marie Laurent.

Louis Pasteur became one of the foremost scientists of his time.

throat. And there was seemingly nothing that could be done about it.

As late as 1849, Hungarian doctor Ignaz Semmelweis had been mocked and bullied by angry colleagues when he claimed that doctors infected their patients by not washing their hands. Semmelweis was fired and became a pariah, ending his days in an insane asylum.

Meanwhile, patients continued to die in droves in labour wards and operating theatres across Europe. The surgeon, as always, put on an old, dirty coat before the operation, so as not to ruin his nice clothes. And if he washed his hands, it was only after the operation had finished.

Idealist was also ambitious

Louis Pasteur was a new type of scientist: meticulous, ambitious, idealistic – and at the same time, skilled at gaining influential allies and raising his own profile.

He'd already made an important discovery during his formative years as a chemist, regarding the formation of crystals in tartaric acid, through systematic laboratory work. This discovery paved the way for a position as a chemistry professor in Strasbourg, where he researched and taught for the next five years.

In 1844, Pasteur became dean of a new faculty of applied sciences at the University of Lille. There, natural scientists would develop practical applications for their research. Pasteur took the young scientists on company visits – and organised evening courses for industrial workers.

Louis Pasteur proved that microorganisms can kill.

He himself researched fermentation and putrefaction processes. His work quickly became invaluable to the wine, brewery, dairy and food industries.

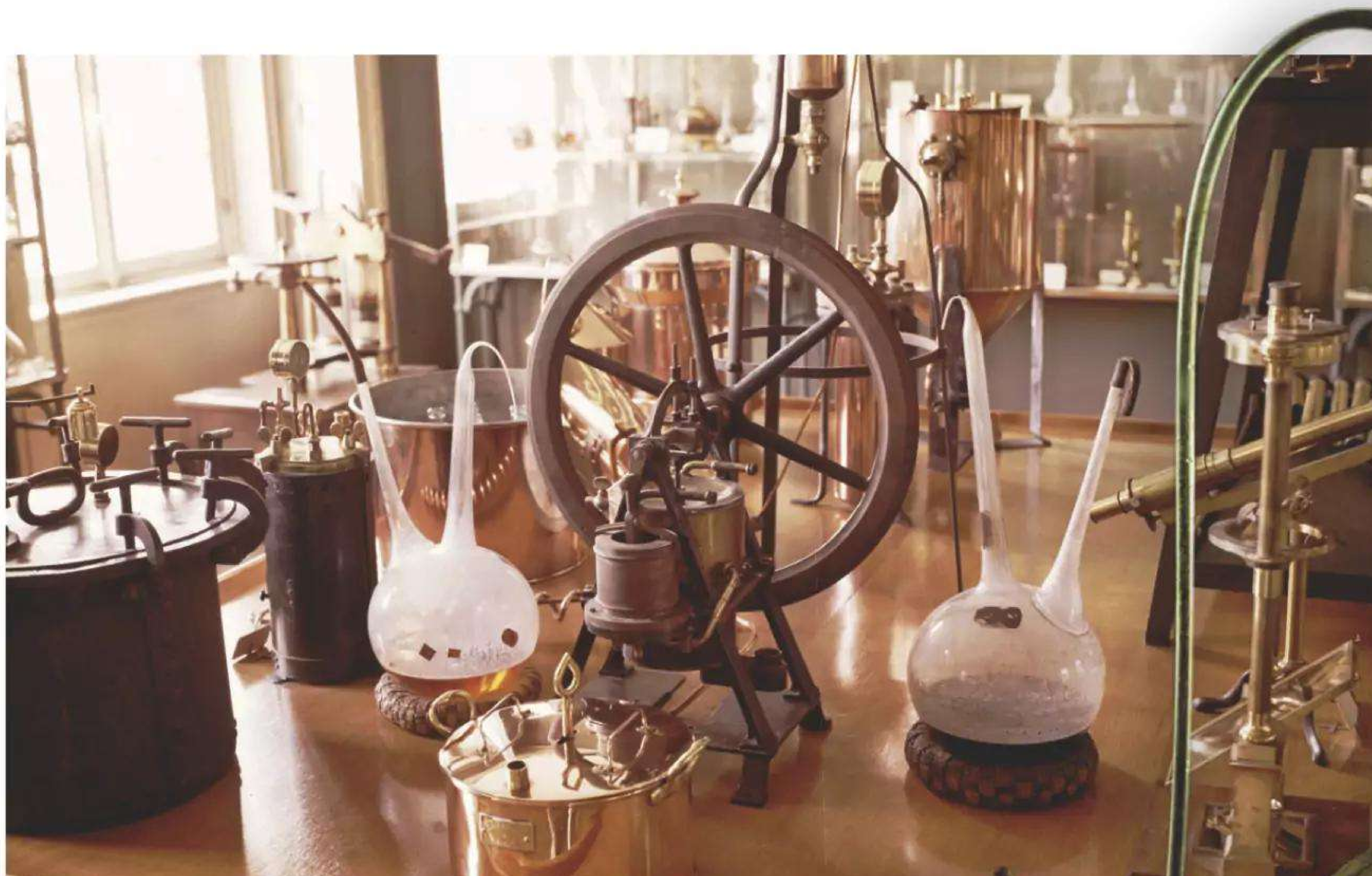
In 1857, Pasteur became director of natural sciences at the elite Parisian university École Normale Supérieure, where he immersed himself in the study of microorganisms. Scientists of the time knew that bacteria existed. They assumed that they miraculously arose "by themselves" from "dead matter".

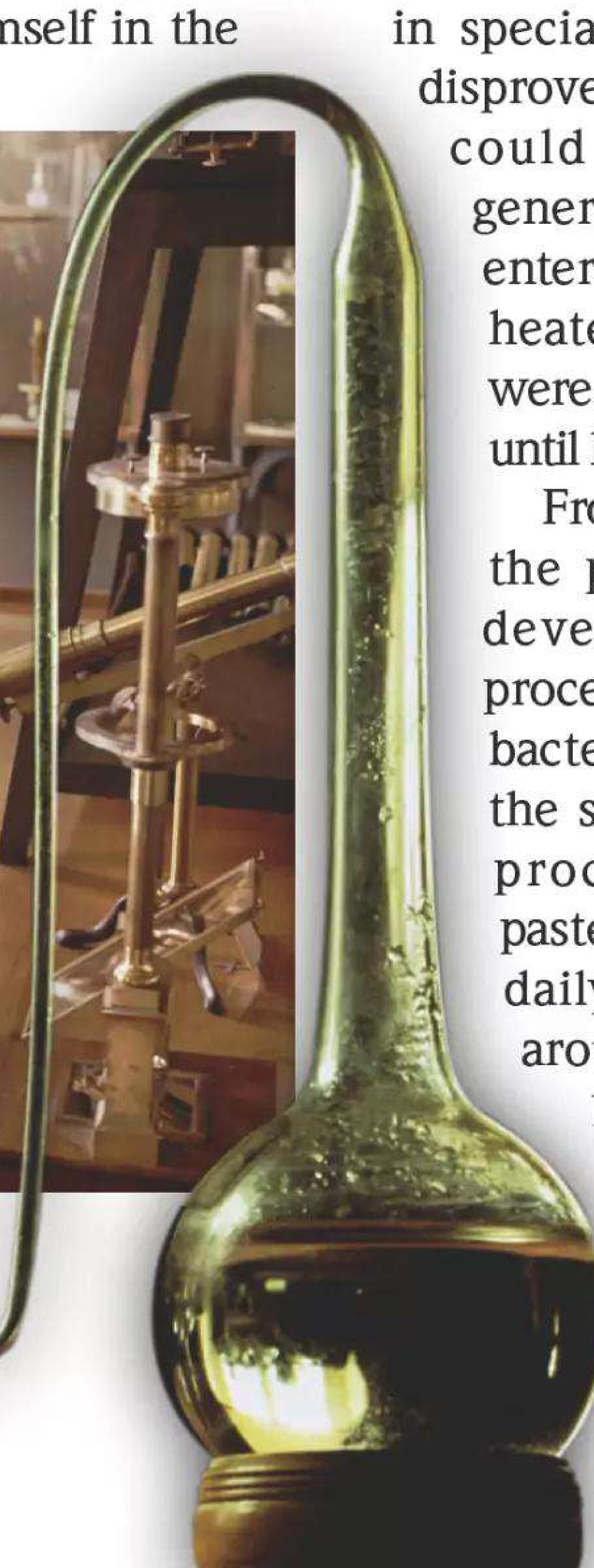
Pasteur was the first to realise after years of experimentation that fermentation and decay are caused by microscopic organisms – yeast cells or bacteria – and in 1860, he proved conclusively that no life could arise from inanimate matter. Today, it seems almost trivial, but at the time, the discovery was revolutionary, because even among early scientists, their thinking was characterised by equal parts science and speculative imagination. A scientist who claimed that not only microorganisms but also flies could arise from "dead matter" was neither castigated nor ridiculed.

Pasteur used experiments with "soup" in special glass flasks to definitively disprove the age-old notion that life could arise by "spontaneous generation": when no impure air entered the soup, which had been heated until all microorganisms were killed, it remained untainted – until he let in fresh, contaminated air.

From there, it wasn't difficult for the practical-minded Pasteur to develop a short-term heating process that could kill pathogenic bacteria in food while extending the shelf life of the product. The process became known as pasteurisation and has been used daily in dairies and breweries around the world for well over 100 years.

In 1865, a chance event sent Pasteur's career in a new direction, putting





Louis Pasteur's centrifuges, flasks and other instruments have been carefully preserved for posterity.

him on the trail of microorganisms as the cause of illness.

A disease that attacked silk larvae was ruining France's silk farmers and destroying the entire silk industry, so Pasteur was asked for help.

Under the scientist's microscope, the eggs and larvae of the silk moths were found to be infected with bacteria. To determine if they were the cause of the disease, Pasteur obtained a batch of healthy larvae. He fed half of them mulberry leaves contaminated with the remains of diseased larvae. The other half were given uncontaminated leaves. The first group of caterpillars became sick and died; the rest remained healthy. So, it was the bacteria that were the culprit.

Pasteur recommended a method to silk growers that selectively bred only healthy moths, which solved the problem. Pasteur hadn't just saved the silk industry; more importantly, he'd established the link between microorganisms and disease.

Hospital visit left Pasteur in shock

Between 1859 and 1866, Louis Pasteur and his wife Marie lost three of their five children; one daughter died from a brain tumour and two from typhus. In 1868, Pasteur himself suffered a stroke that left him paralysed on his left side. Nevertheless, he refused to give up his work. On the contrary, the death of his daughters became a strong personal driving force – he wanted an end to both disease and infant mortality!

When Germany attacked France in 1870, Pasteur's son, Jean-Baptiste, was in the army. Like many other soldiers, he contracted typhus. However, he recovered and was visited by his father in the military hospital. While there, Louis Pasteur was shocked to see the unhygienic conditions coupled with the stench of rot from the soldiers' open wounds.

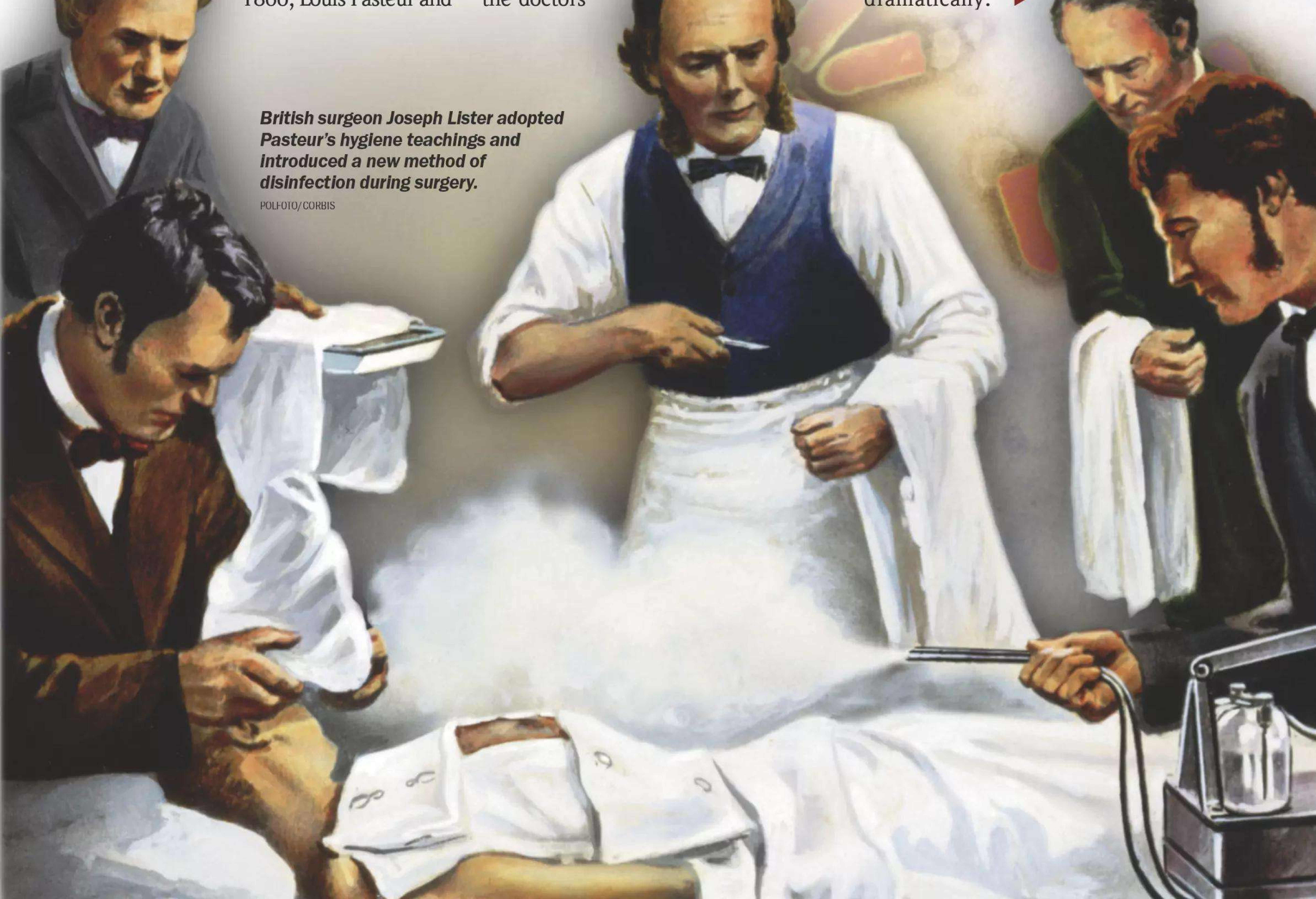
He went to the hospital officials and tried to explain to them that the filthy conditions gave bacteria far too good an opportunity to grow, resulting in unnecessary deaths. But the doctors refused to listen to such nonsense. Monsieur Pasteur had clearly not studied medicine!

Pasteur's teachings on hygiene ended mass deaths in hospitals.

This complete lack of awareness infuriated Pasteur. He campaigned for surgeons to wash their hands, put on clean gowns, and ensure sterile instruments and clean operating theatres. And unlike the discredited and ignored Semmelweis, Pasteur was armed with solid, scientific arguments – plus all the authority of his international reputation.

Pasteur's persistence had far-reaching consequences when British surgeon Joseph Lister became aware of his work. By then, surgeons had learned to anaesthetise and could therefore perform major operations. But even when the operations went perfectly, at least half of patients died from infections around the wounds.

Lister invented a tool that nebulised a solution of disinfectant carbolic acid in the operating room, causing mortality rates to drop dramatically. ▸



British surgeon Joseph Lister adopted Pasteur's hygiene teachings and introduced a new method of disinfection during surgery.

POLFOTO/CORBIS

Eventually, even French doctors started doing what Pasteur suggested.

Anthrax gave insights into immunity

After his stroke, Louis Pasteur could no longer teach. However, the French government recognised his efforts by granting him a fixed annual salary so that he could conduct research, and Pasteur eventually devoted all his energy to studying diseases and their causes.

In 1877, anthrax – a contagious disease among cattle – was widespread in herds across much of France. Pasteur found that some animals were more severely affected than others; he injected two cows with a heavy dose of anthrax bacteria and expected them both to die.

To his surprise, they both remained completely healthy. It turned out that both animals had already had the disease. Was that why they didn't get sick again? He wondered if other animals could also be protected if they were given a dose of attenuated anthrax that caused a mild attack. After many trials, Pasteur managed to create a weakened strain of anthrax that he could inject into cows and sheep. When they were later put together with very sick animals, the test animals remained healthy – they'd become immune to anthrax.

The rabies vaccine saved 2,500 people in just over a year.

Pasteur's vaccine trials prompted other scientists to contact him. One day, he was visited by a doctor who asked him to try to find a cure for rabies – a disease that was feared by the population and was fatal in 100 per cent of cases.

Pasteur knew that rabies affects the brain. He hypothesised that it could be a bacterial attack. So, Pasteur and his assistants began experiments where they injected brain matter from dogs that had died of rabies into healthy dogs. They also fell ill and died – but despite hours of staring under the microscope, the puzzled Pasteur was unable to find a bacterium that could be linked to the disease.

There were natural reasons for this: it was not a bacterium at all, but a virus that microscopes were too weak to detect.

Nevertheless, Pasteur devised a method to fight the invisible pathogen: he dried the tissue of sick animals in bottles with sterilised air to weaken the microorganism. The dried tissue was injected into healthy dogs and rabbits. They didn't get sick – not even after receiving a shot of pure, unadulterated rabies after some time.

The vaccine had been found!

New cries for help

Pasteur wasn't yet ready to test his vaccine on humans – it was too risky. Nevertheless, a doctor persuaded him to try to help a girl who was hospitalised with rabies. The vaccine was her only chance. Reluctantly, Pasteur stuck the needle in her.

The girl didn't make it, and although Pasteur was deeply affected by her death, he managed to extract tissue from her brain and inject it into rabbits. The animals died quickly. This led Pasteur to believe that the girl's disease had simply been too advanced for her to be saved.

It was while Pasteur was pondering these thoughts that Madame Meister approached him one summer day in 1885 with her son Joseph and asked him for help.

Pasteur agreed; Joseph's dog bites were so fresh that he had not yet

Rabies still claims over 40,000 lives a year

Louis Pasteur's vaccine can save everyone – but only if given in time. Rabies outbreaks can spell certain death even today.

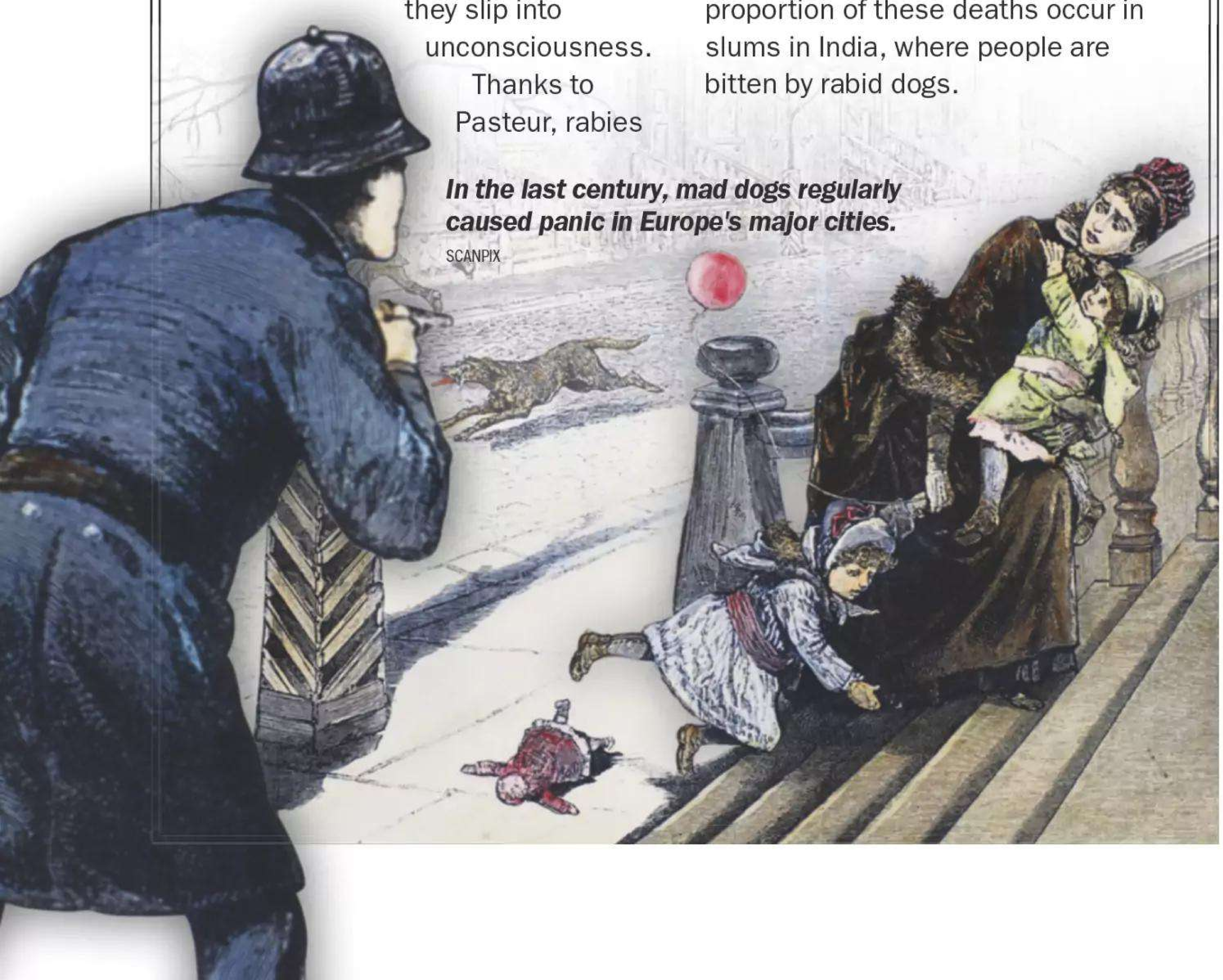
Just over 125 years ago, a single loose dog acting aggressively could clear a busy street in an instant. People fled in panic, fearing rabies – canine distemper.

Rabies is a viral disease that attacks the brain. Sick animals become aggressive and eventually die. For animals and humans alike, there's no escape once the disease has broken out – rabies is fatal in 100 per cent of cases. Sufferers go into convulsions when they try to drink and gradually weaken until they slip into unconsciousness.

Thanks to Pasteur, rabies can now be prevented with vaccination. And even if an animal or human has been bitten and infected, the vaccine can effectively prevent the disease from developing – so long as it's given in time.

The UK has technically been rabies-free for decades, but in most of the world the disease is still found in wild animals. And in humans.

Rabies outbreaks aren't as rare as many Brits might think. Every year, rabies claims somewhere between 40,000 and 70,000 lives. A huge proportion of these deaths occur in slums in India, where people are bitten by rabid dogs.



In the last century, mad dogs regularly caused panic in Europe's major cities.

SCANPIX

developed symptoms. Over the next ten days, Pasteur gave the boy 13 injections of rabies virus of increasing strength. The last injection was so powerful that it would kill a lab dog in a few days. Pasteur spent a sleepless night – would Joseph live or die?

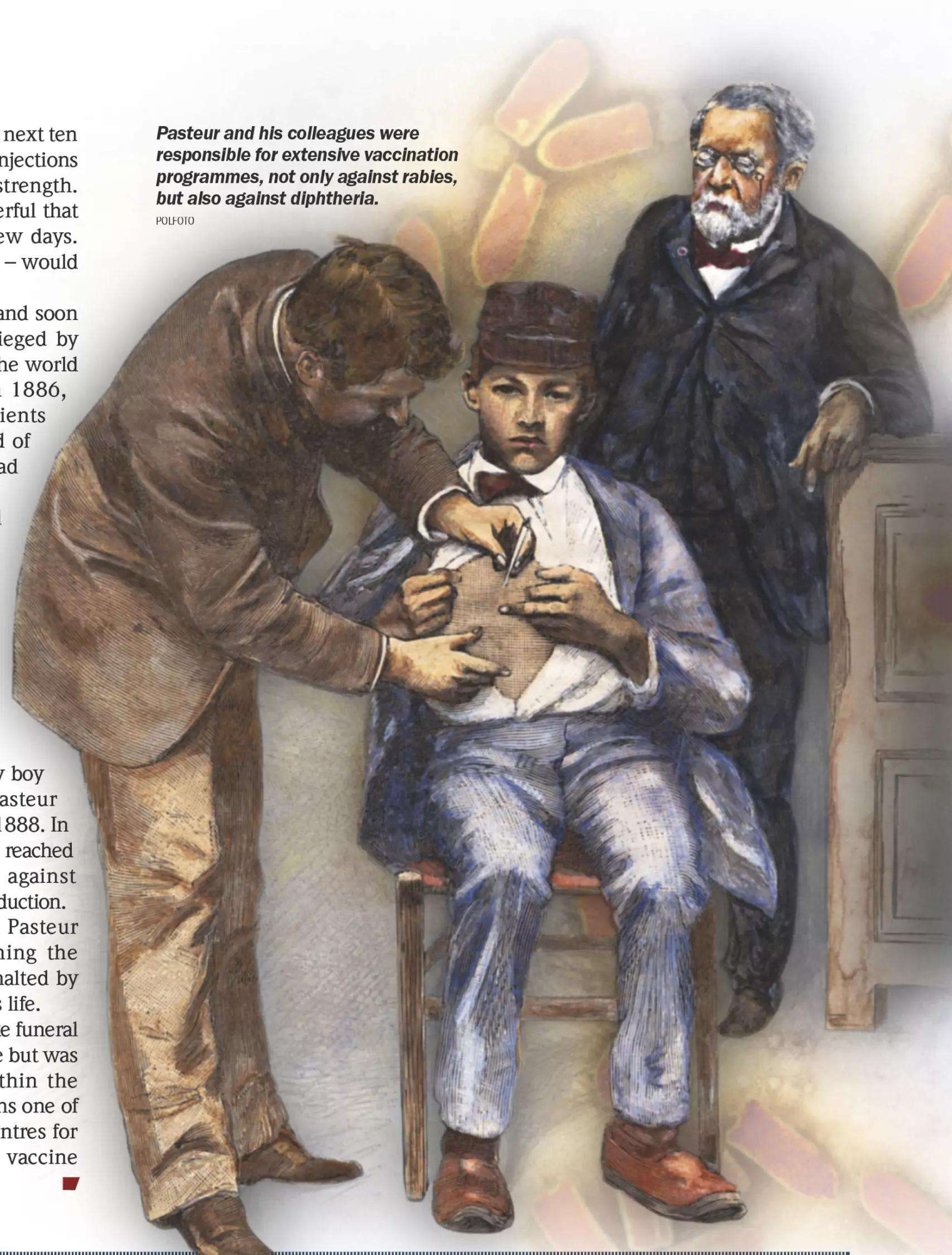
The boy remained healthy and soon Pasteur's laboratory was besieged by rabies sufferers from all over the world seeking treatment. By March 1886, Pasteur had treated 350 patients and lost only one. By the end of 1886, the rabies vaccine had saved over 2,500 people.

When Louis Pasteur turned 70 in 1892, guests from all over the world flocked to the Sorbonne University in Paris, where praise and medals of honour rained down on him. Prior to this, Pasteur had suffered another stroke and his son had to read his acceptance speech.

After the party, the birthday boy continued working at the Pasteur Institute, which had opened in 1888. In 1894, the institute's researchers reached the point where a vaccine against diphtheria could be put into production.

The following year, Louis Pasteur threw himself into researching the plague's bacterium, but was halted by another stroke that claimed his life.

The scientist was given a state funeral in the Cathedral of Notre-Dame but was later reburied in a crypt within the Pasteur Institute, which remains one of the world's most important centres for microbiological research and vaccine production to this day.



Pasteur and his colleagues were responsible for extensive vaccination programmes, not only against rabies, but also against diphtheria.

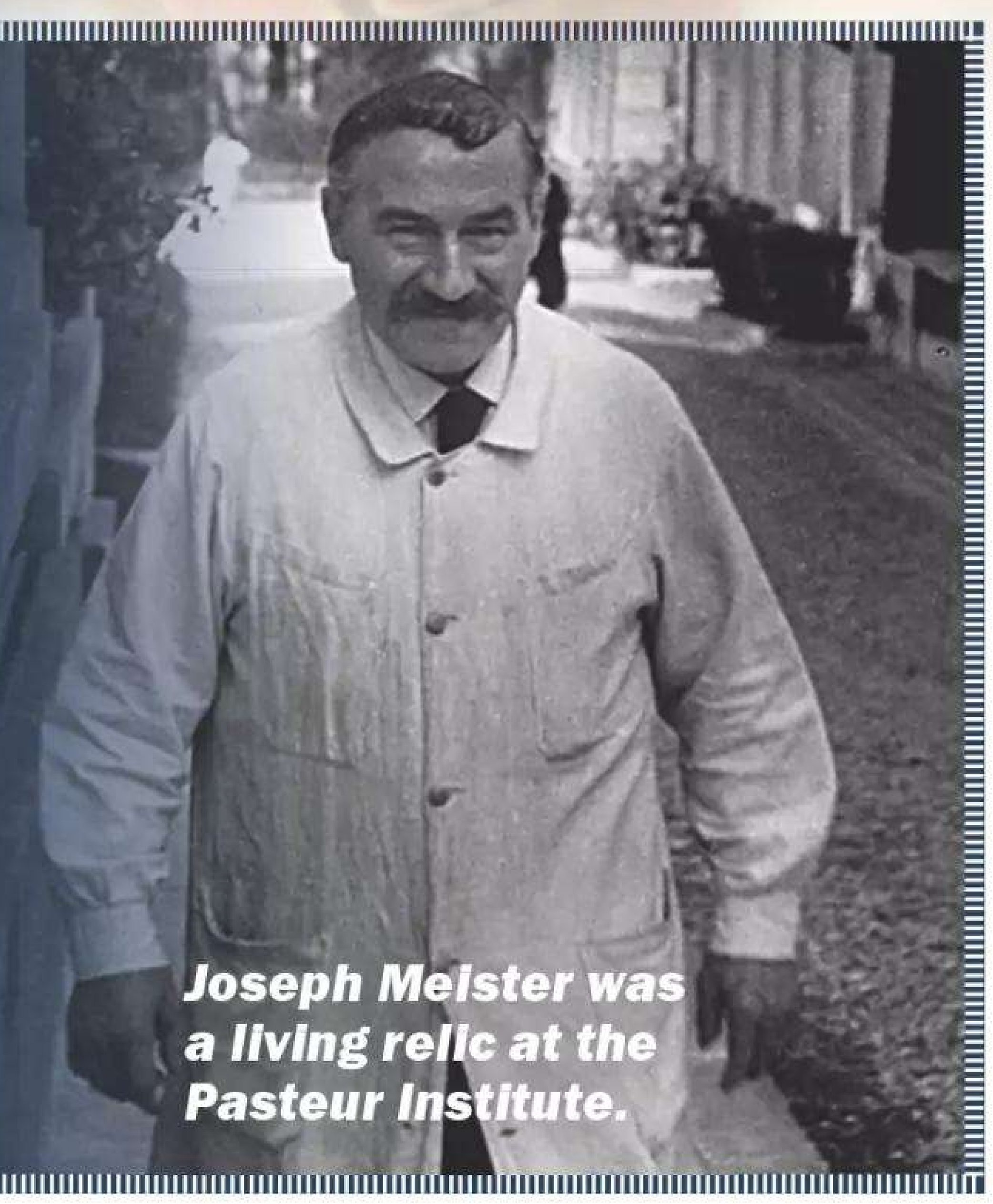
POLFOTO

Pasteur took a big risk

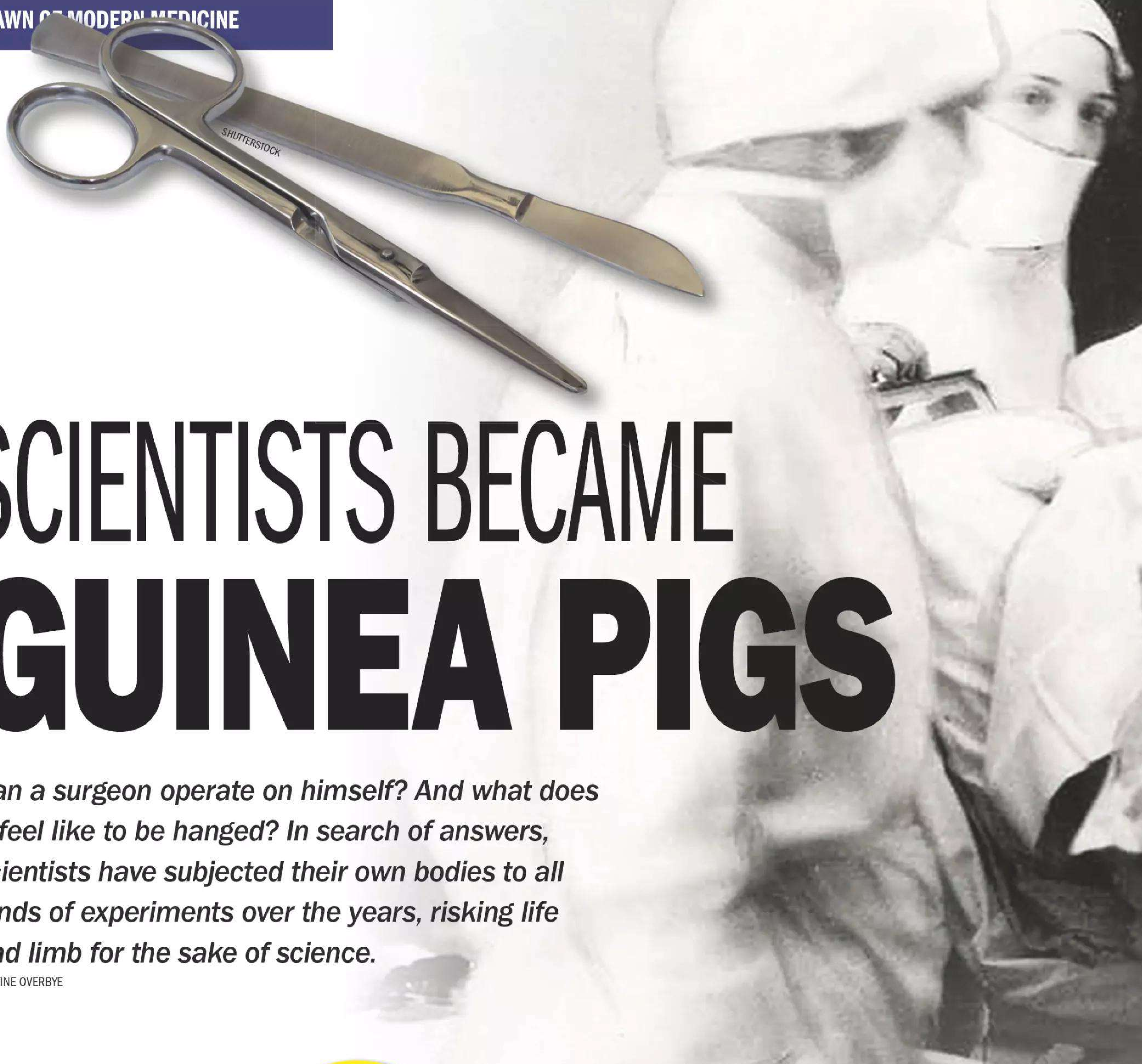
As a chemist, Pasteur was not authorised to provide medical treatment. In fact, he committed a criminal offence when he vaccinated nine-year-old Joseph Meister with a dose of moderately attenuated rabies that could have killed a laboratory dog.

Pasteur took the risk because he believed it was the boy's only chance. And because the outcome was good, no one asked critical questions afterwards: the boy was saved and Louis Pasteur became one of the great heroes of science. Meister was later employed as an adult as a janitor at the Pasteur Institute. He held the job for most of his life. But when the Germans conquered Paris in the summer of 1940, he shot himself, aged 64, with his World War I service pistol.

Legend has it that Meister took his own life in despair after failing to prevent German soldiers from entering the crypt of the Pasteur Institute, the final resting place of the man who'd saved his life 55 years earlier.



Joseph Meister was a living relic at the Pasteur Institute.



SHUTTERSTOCK

SCIENTISTS BECAME GUINEA PIGS

Can a surgeon operate on himself? And what does it feel like to be hanged? In search of answers, scientists have subjected their own bodies to all kinds of experiments over the years, risking life and limb for the sake of science.

BY STINE OVERBYE

JEAN CHARLOT/THE METROPOLITAN MUSEUM OF ART

The foulest

Doctor drank patients' vomit

To prove that yellow fever wasn't contagious, US doctor Stubbins Ffirth resorted to unusual methods in the early 19th century.

He cut small wounds in his arm and poured fresh black vomit from patients with yellow fever into them. When the doctor didn't fall sick, he went a step further and dripped vomit into his eyes.

Encouraged by his success so far, Ffirth resorted to more drastic means – he drank a whole glass of vomit and finally completed the experiment by smearing his body with the saliva, sweat, blood and urine of people with yellow fever. Ffirth remained healthy as ever – conclusive proof to the doctor that he was right. But while he was technically correct, Ffirth failed to learn how yellow fever is transmitted.

Black vomit is a symptom of yellow fever.

HE FOUND OUT:
Ffirth concluded that yellow fever wasn't transmitted from person to person, but didn't discover that it's transmitted via mosquito bites.

Created path from

When heart surgery was in its infancy, doctors debated whether a patient could survive having their heart examined with a catheter inserted through a vein. Most assumed that such a procedure would be fatal, but not 25-year-old German doctor Werner Forssmann, who worked at a hospital in Eberswalde near Berlin.

During a lunch break on a summer day in 1929, he decided to try the procedure on himself. Forssmann inserted a 65-centimetre-long thin catheter into a vein in his arm and from there directed it into the right atrium of the heart. In the hospital's X-ray department, he was able to follow the catheter's journey to its destination as well as achieve his main goal – to prove the procedure was

The nurses didn't know how to deal with Kane while he was in surgery.

CREATIVE COMMONS

The bravest

OPERATED on his own gut

In 1921, a surgeon wondered if local anaesthesia was enough for a patient during an operation. Instead of trying the procedure on others, he put himself under the knife.

In February 1921, experienced surgeon Evan O'Neill Kane decided to become his own patient. He wanted to remove his appendix and use the opportunity to test whether local anaesthesia was sufficient for the procedure.

With a mountain of pillows behind his back and a mirror to lean on, the 60-year-old Kane lay on the operating table, injected himself with a local anaesthetic and cut a hole in the skin of his stomach to the appendix.

Half an hour later, the operation was over – and Kane was left with an appendix and an important lesson: the local anaesthetic had removed the pain of the surgery.

Kane recovered quickly from the procedure and encouraged by his success, operated on himself again 11 years later – this time for an inguinal hernia. The far more complicated procedure took two hours and was also successful.

HE FOUND OUT:

It's possible to operate on a conscious patient under local anaesthesia – a generally safer method than general anaesthesia.

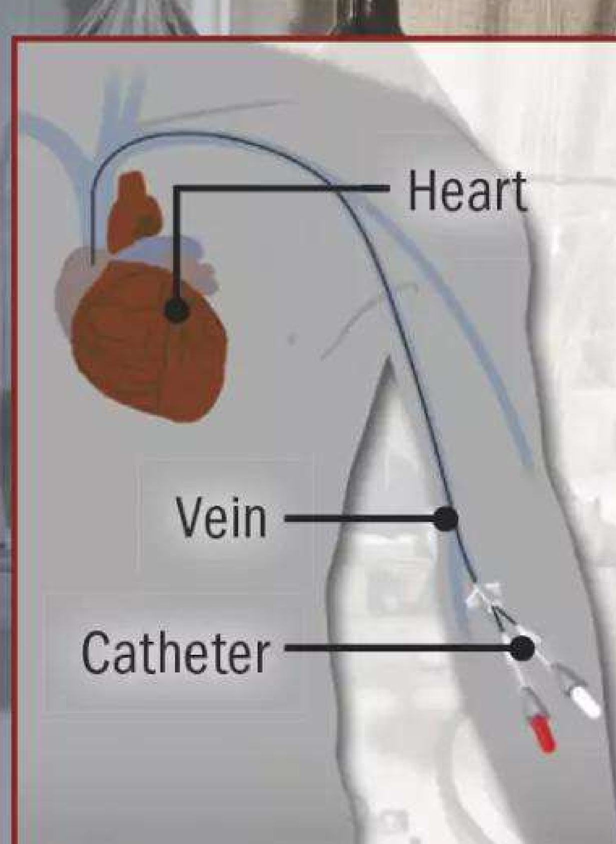
elbow to heart

possible and that he survived his experiment. Shortly afterwards, Forssmann published a thesis on cardiac catheterisation, but failed to receive any recognition. Colleagues condemned the technique because, in their opinion, it was far too risky.

In the 1940s, however, Forssmann finally convinced the medical world of the benefits of the cardiac catheter, and today the German's technique is widely used in heart clinics across the globe.

HE FOUND OUT:

Forssmann made it possible to measure blood pressure in the heart, among other things. In 1956, he was awarded the Nobel Prize for inventing the technique.



CATHETER FOLLOWED BLOOD FLOW

Werner Forssmann opened a hole in his vein at his elbow, where he inserted the catheter. Using a fluoroscopy in the hospital's X-ray department, he was able to see how the catheter was guided by the blood flow towards his heart, ending up in his right ventricle.

BETTMANN, CORBIS, ALL OVER & ALLAN HØIEN

The boldest

Forssmann specialised in urology and the urinary tract after World War II.

Piloted a sled at 1,000 KM/H

Violent forces impact a pilot who is catapulted out of a fighter jet, so John Stapp investigated whether it's possible to survive the extreme forces generated.

The last thing John Stapp had to say before the Sonic Wind I rocket sled accelerated away was: "I assure you, I'm not looking forward to this."

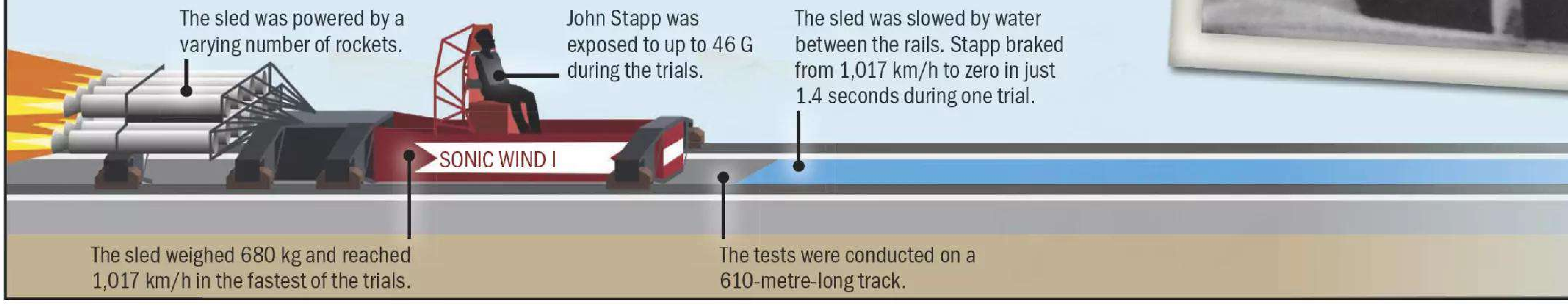
Stapp was a doctor with the US Air Force, and in the hope of discovering whether a fighter pilot could survive being catapulted out of a supersonic aircraft, Stapp had offered himself up as a guinea pig. He repeatedly allowed himself to be strapped into a rocket sled that hurtled along a railway track.

One December day in 1954, Stapp was about to embark on his 29th trip, the wildest yet, where thanks to the sled's nine rockets, he would reach a speed close to the speed of sound. During previous experiments, Stapp had broken his coccyx, fractured several ribs and suffered eye bleeds, so he understood all too well that he was risking life and limb.

And he didn't escape the ride unscathed. The braking was so abrupt that the blood vessels in Stapp's eyes burst and his eyes bulged out of their sockets. The daredevil temporarily lost his sight, but he could take pride in not only being the fastest man on Earth, but also in proving that fighter pilots could survive the G-forces of extreme acceleration and violent braking.

HE FOUND OUT:
Pilots can survive the g-forces generated when ejected from supersonic aircraft.

The lightning-fast sled – Sonic Wind I



ALLAN HØJEN

Survived on bread, cabbage and potatoes

During World War II, Elsie Widdowson created an experimental diet of bread, potatoes and cabbage, foods that were almost always available all year round in her native Britain.

For three months, Widdowson lived on this diet. The kilos rattled off her, but to prove the diet was sufficient, she headed up to the Lake District National Park, where she burned off 4,700 kilocalories in one day by hiking 58 kilometres and climbing two kilometres up the mountains.

Widdowson survived the ordeal and concluded that the diet could meet the body's needs, so long as calcium was added to it.

SHE FOUND OUT:
Her research formed the basis of the British government's rationing policy during World War II.

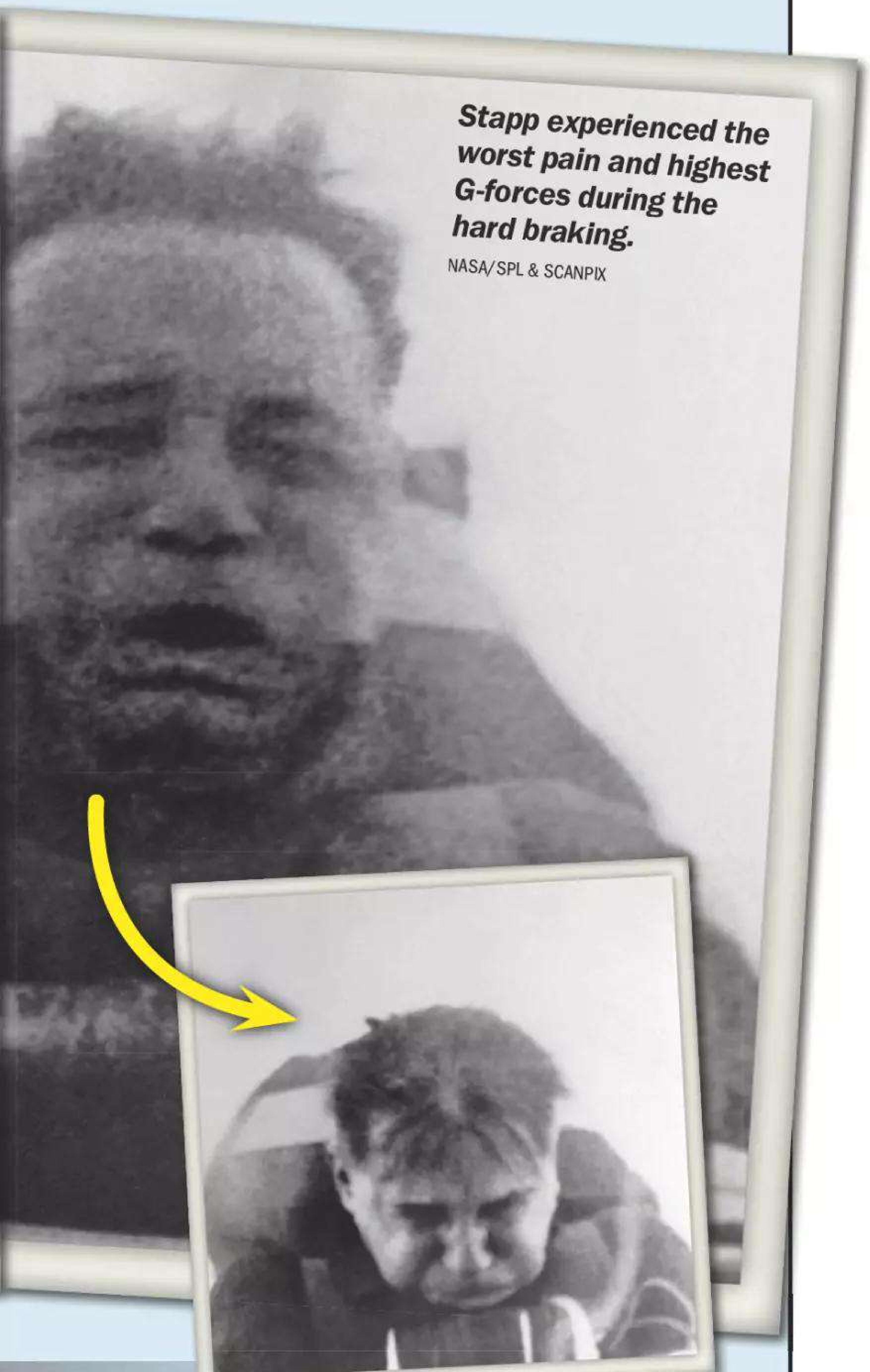
Widdowson also conducted trials where she took minerals and vitamins intravenously.
BRITISH NUTRITION FOUNDATION & CREATIVE COMMONS

SHUTTERSTOCK

Hanged himself (again

In the early 20th century, Romanian forensic scientist Nicolae Minovici embarked on a series of neck-breaking experiments to understand what it feels like to be hanged. From lying on a couch and tightening a noose around his own neck, the experiments evolved to the point where he dangled two metres above the ground in a noose. The discomfort was intense for Minovici, yet he continued with his experiments.

HE FOUND OUT:
How it felt to be hanged. Minovici described the sensation in a detailed 200-page study.



Stapp experienced the worst pain and highest G-forces during the hard braking.

NASA/SPL & SCANPIX

Stapp was often so weakened after the trials that he had to be helped from the sled.

The sorest

Bitten by black widow

In the 1930s, scientists were divided over whether the black widow's bite was toxic to humans. Thirty-two-year-old medical professor Allan Walker Blair decided to take matters into his own hands and let himself be bitten by a female spider.

Blair's muscles cramped, and he gasped for breath. Writhing in pain and sweating profusely, his blood pressure plummeted. The professor was rushed to hospital, and after several days of agony, a doctor determined that he had never seen a patient suffer so much. Blair only recovered after a week, during which time he'd repeatedly only accepted morphine.

In the months following the bite, his entire body itched and the skin on both hands and feet felt like it was burning. Blair stated that "the venom injected by the bite of the adult female spider … is dangerously poisonous for man".

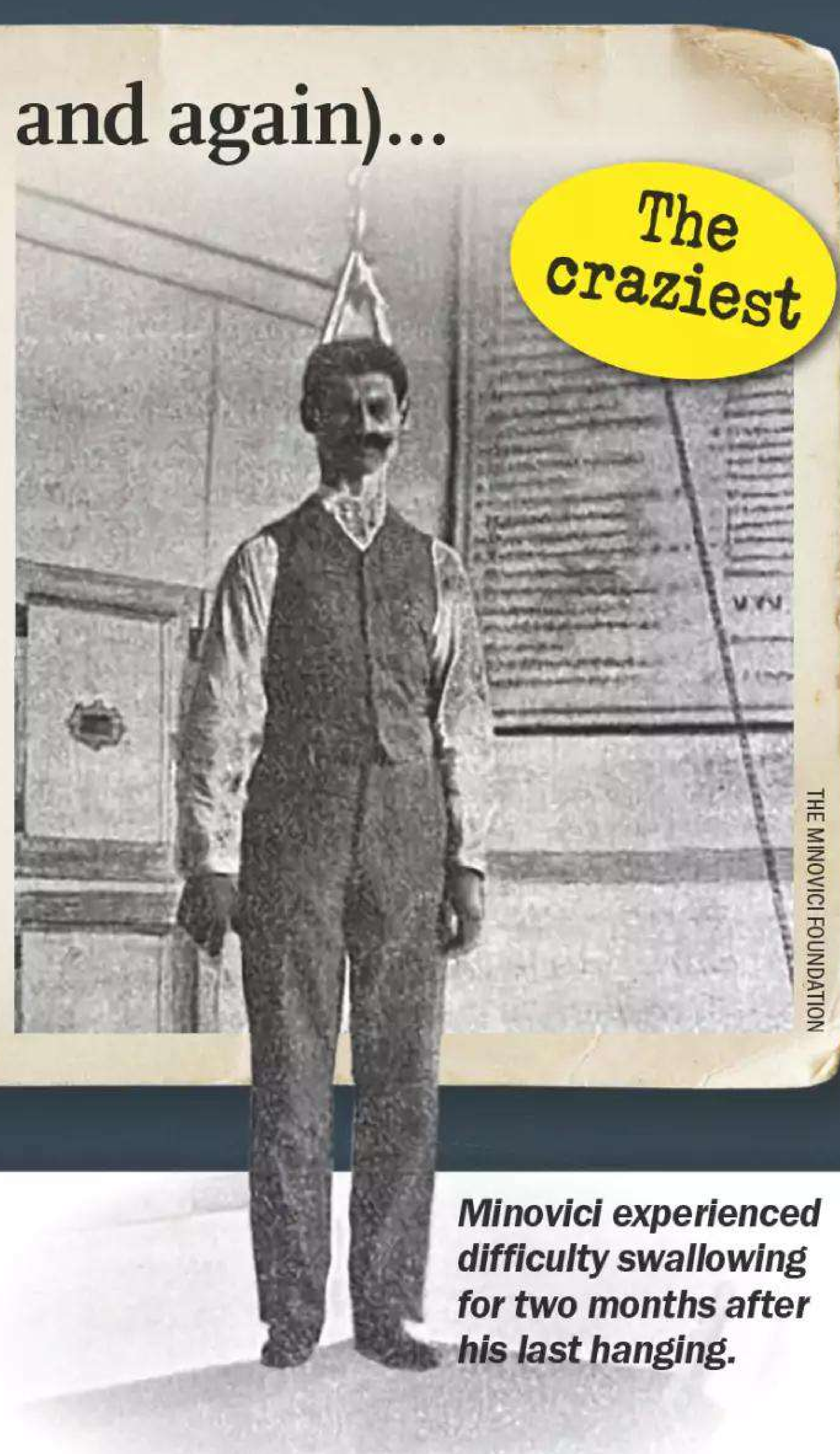
HE FOUND OUT:
He convinced many contemporary sceptics that a black widow's bite is potentially fatal to humans.

It's the alpha-latrotoxin venom that makes black widows dangerous.

STEPHAN HOEROLD & GETTY IMAGES

and again)...

The craziest



THE MINOVICI FOUNDATION

Minovici experienced difficulty swallowing for two months after his last hanging.

Drank bacteria-laced "soup"

In the early 1980s, young Australian researcher Barry J Marshall and his colleague J Robin Warren set out to prove that ulcers are caused by helicobacter bacteria – not stress or strong coffee as previously thought.

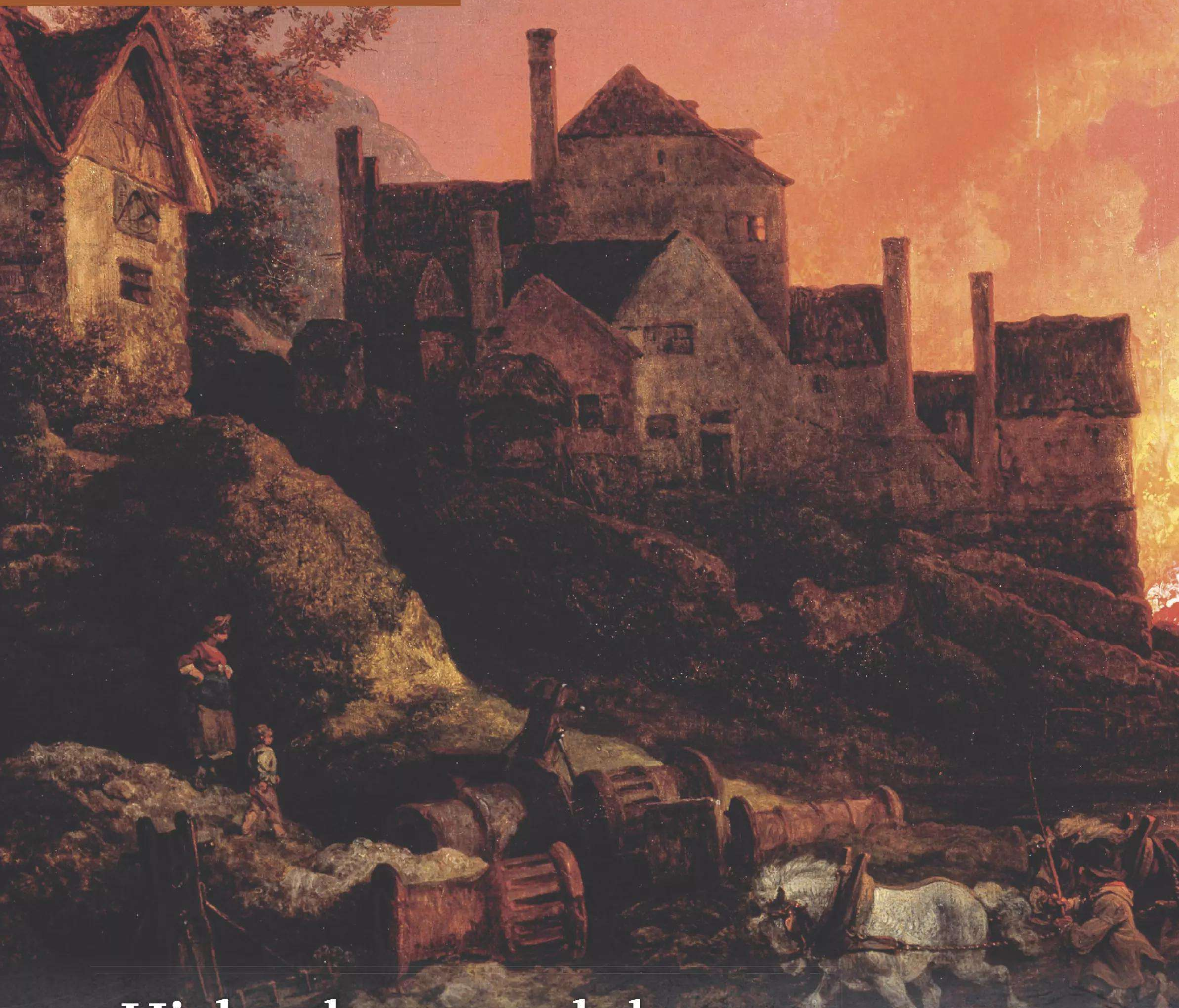
But when doctors and scientists around the world mocked the two and labelled them as quacks, Marshall took drastic measures to prove himself right. He drank a big shot of helicobacter bacteria, which in his own words "just tasted like soup". The ulcer erupted and bacteria swarmed in the inflamed area. The sceptics cringed and acknowledged that the two scientists were right.

THEY FOUND OUT:
Their research helped make it possible to treat stomach ulcers with a relatively simple course of antibiotics.

The sickest

REUTERS/SCANPIX

Barry J Marshall (left) and J Robin Warren received a Nobel Prize in 2005 for their discoveries.



Higher, longer and cheaper:

THE 2ND IRON

BY TORSTEN WEPER

In the 18th century, a British manufacturer discovered how to produce large quantities of cheap, high-quality iron. Now engineers could construct longer bridges, taller towers and faster ships than ever before.

The cradle of industry lay in Coalbrookdale, where Abraham Darby built his blast furnace in 1709.
WORLD HISTORY ARCHIVE/IMAGESELECT

AGE

ENGINEERS SET NEW RECORDS

GRANGER/IMAGESELECT

Abraham Darby ran a small ironworks where he manufactured cast-iron household utensils.

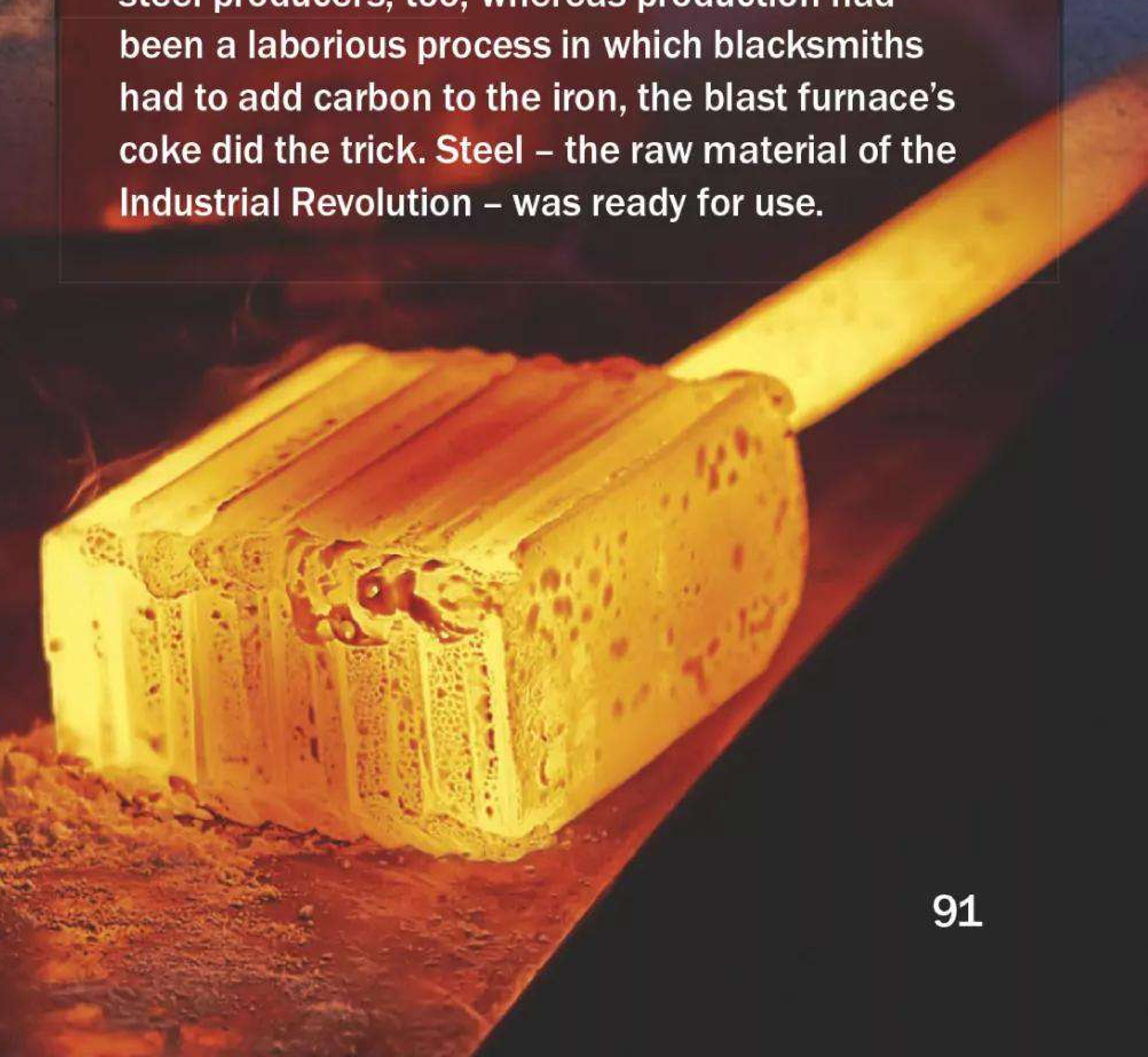
Coke accelerated industrialisation

Since ancient times, blacksmiths have made steel by alloying iron with coal. In the 18th century, the process was finally simplified.

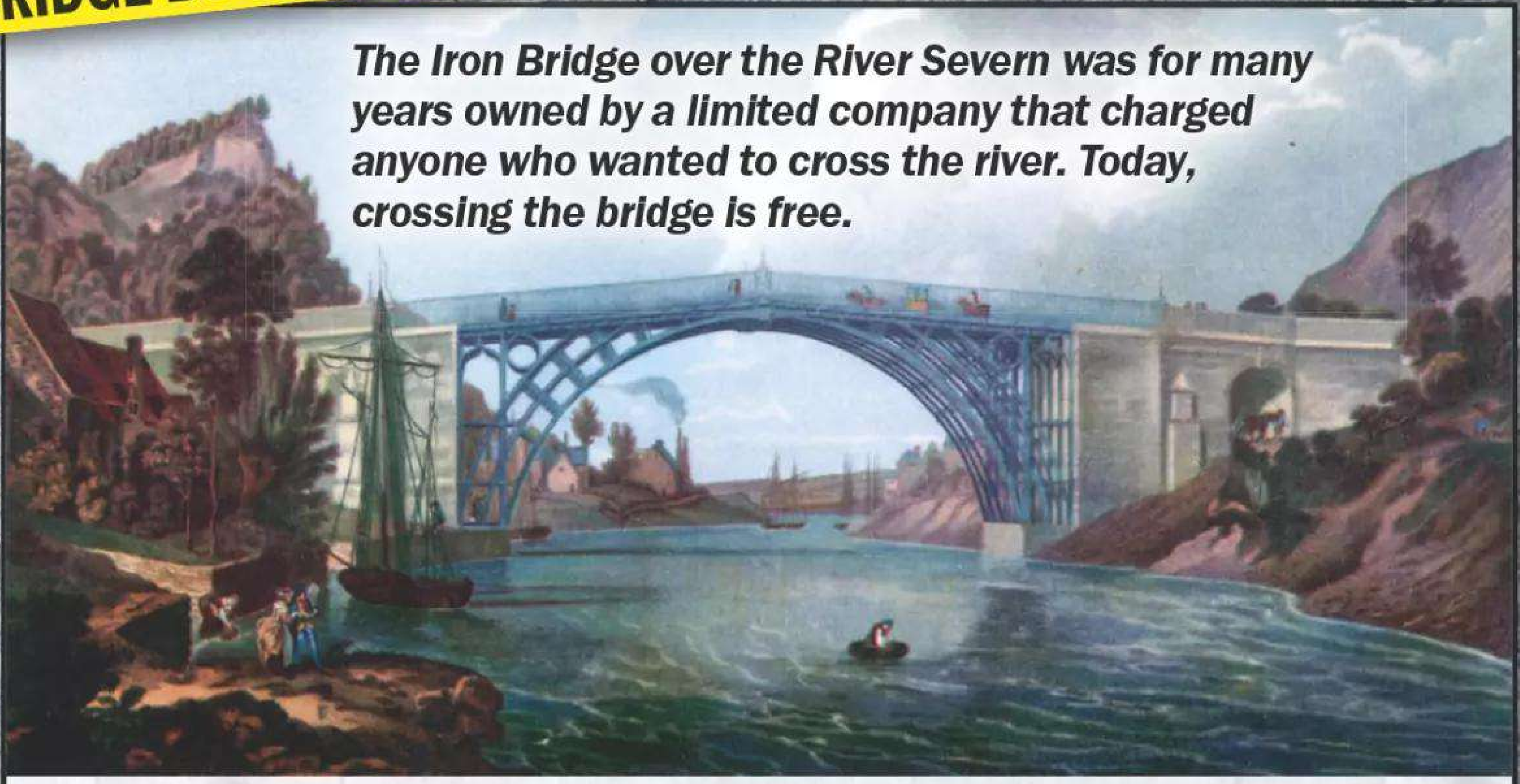
The subsoil beneath Coalbrookdale in the heart of England was rich in coal. From the 16th century, iron manufacturers and foundry owners established their industries here.

Among them was Abraham Darby. In 1709, he discovered that he could use coke instead of charcoal in his blast furnace to extract iron. Coke didn't cost nearly as much, so Darby produced iron much more cheaply. At the same time, he achieved a higher temperature in the furnace, and soon Darby's blast furnace was producing three times as much iron as before.

Darby's coke-fired blast furnace later benefited steel producers, too; whereas production had been a laborious process in which blacksmiths had to add carbon to the iron, the blast furnace's coke did the trick. Steel – the raw material of the Industrial Revolution – was ready for use.



BRIDGE BUILT OF IRON



The Iron Bridge over the River Severn was for many years owned by a limited company that charged anyone who wanted to cross the river. Today, crossing the bridge is free.

THE HISTORY EMPORIUM/IMAGESELECT

Iron Bridge was built by carpenters

The English Midlands – and in particular Shropshire, where Abraham Darby built his blast furnace – became a centre of the Industrial Revolution during the 18th century. The area was rich in coal and iron ore, but the transport of goods was hampered by the River Severn.

The only way to cross the river was by ferry. Local industrialists, led by Darby's grandson, Abraham Darby III, wanted a faster crossing and in 1775 presented plans for a cast-iron bridge.

No one had experience with large iron structures. Therefore, the bridge, 30 metres long and 18 metres high, was constructed as though it were a wooden bridge. Each part of the bridge was moulded separately, and the majority of the 800 parts were joined together using pins – a technique that carpenters had used for thousands of years. The construction took a total of four years and went £3,000 over budget, money that Abraham Darby III paid out of his own pocket.

IRON SHIP WITH SCREW

SS Great Britain was fastest across the Atlantic

British engineer Isambard Kingdom Brunel rose to fame in 1838 when he opened the Great Western Railway between London and Bristol.

But Brunel was also convinced that iron was the future of shipping, too. His idea was met with great scepticism, but the Great Western Steamship Company, for whom Brunel had previously built ships, believed in him.

They commissioned the SS *Great Britain*. A ship that would not only be the largest ship in the world, but also the first ocean-going iron ship powered by propellers.

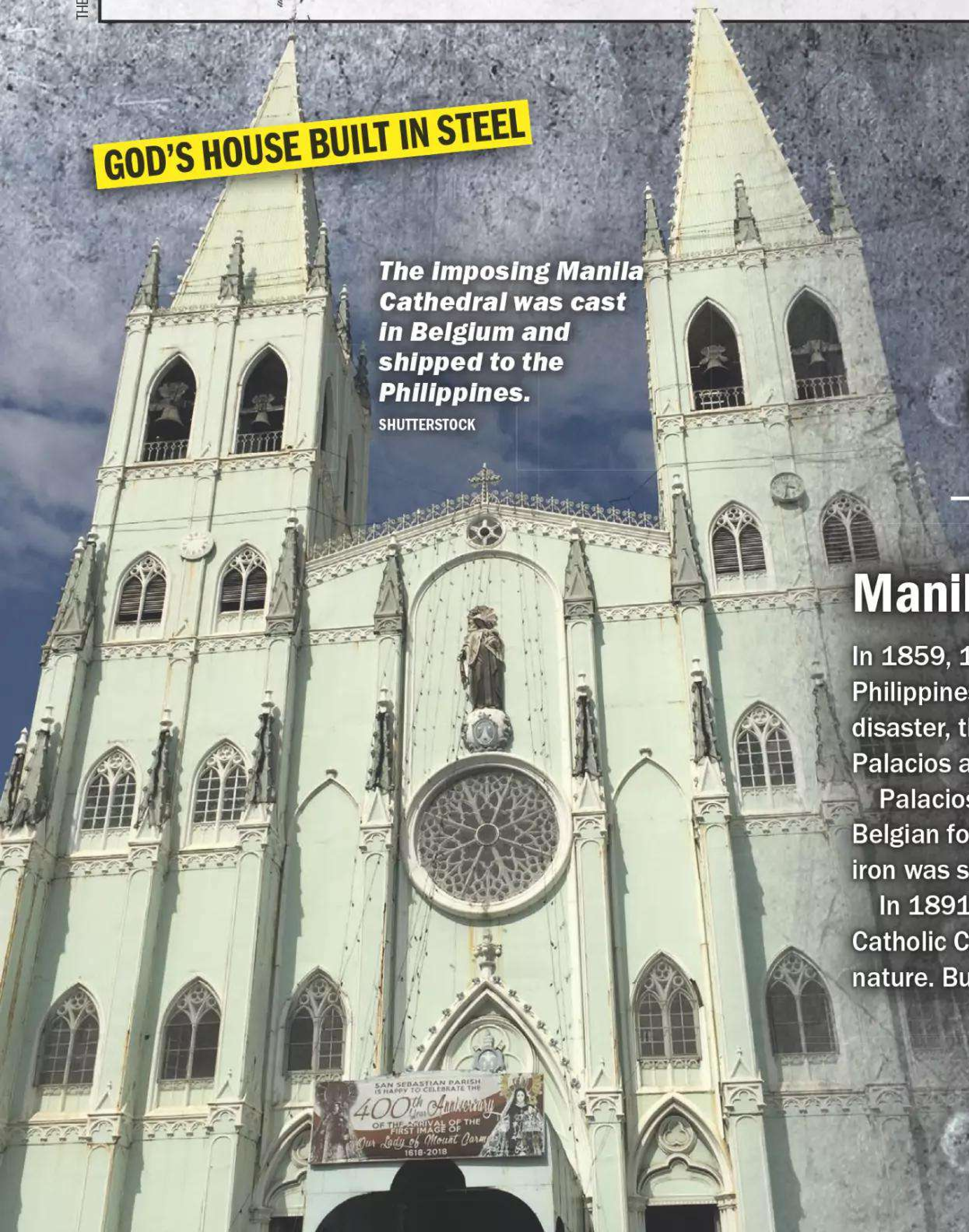
The *Great Britain* was built in the same way as a wooden ship. But looks were the only thing the ship had in common with her predecessors: she was 25 metres longer than the largest ship to date – and her weight of 1,961 tonnes made her the heaviest in the world. The ship was equipped with a screw propeller five metres in diameter, powered by a 1,000-hp steam engine.

Despite many prophesying catastrophe, the ship was a great success on her launch in 1843. She travelled the Bristol-New York route and broke the speed record. Now the voyage could be completed in 14 days instead of a month and a half with a sailing ship.

WIKIMEDIA COMMONS

SS Great Britain *had room for approximately 250 passengers. Since 1970, she has been restored and today serves as a museum ship in Bristol, UK.*

GOD'S HOUSE BUILT IN STEEL



The imposing Manila Cathedral was cast in Belgium and shipped to the Philippines.

SHUTTERSTOCK

Manila Cathedral was quake-proof

In 1859, 1863 and 1880, the San Sebastian Basilica in Manila, Philippines, was destroyed by fire and earthquakes. After the last disaster, the church's pastor sought out Spanish architect Genaro Palacios and pleaded with him to build a more robust church.

Palacios proposed one made of steel. Once the idea was approved, a Belgian foundry manufactured the various parts. A total of 520 tonnes of iron was shipped to Manila with a team of Belgian engineers.

In 1891 – after three years of work – the church was completed. The Catholic Church declared the construction a victory over the forces of nature. But today it is badly corroded with rust.

WORLD'S TALLEST TOWER

Tower was 18,038-piece kit

UNIVERSITÄTS UND LANDESBIBLIOTHEK DARMSTADT

Insults rained down on Gustave Eiffel when he unveiled plans for a 300-metre-high tower in the centre of Paris. But millions of people still visit it every year.

In the 1880s, engineer Gustave Eiffel found it difficult to gain interest in his groundbreaking wrought iron tower. The organisers of the Barcelona World's Fair (1888) rejected him on the grounds that it was too weird and too expensive.

Paris, set to host the 1889 World's Fair, said yes to Eiffel. This led to a storm of protest, and leading artists signed a complaint against "this disgusting column of bolted tin" that would dominate the Paris cityscape "like a gigantic black factory smokestack".

Despite the protests, construction began in 1887 – but on the condition that the tower would be demolished after 20 years.

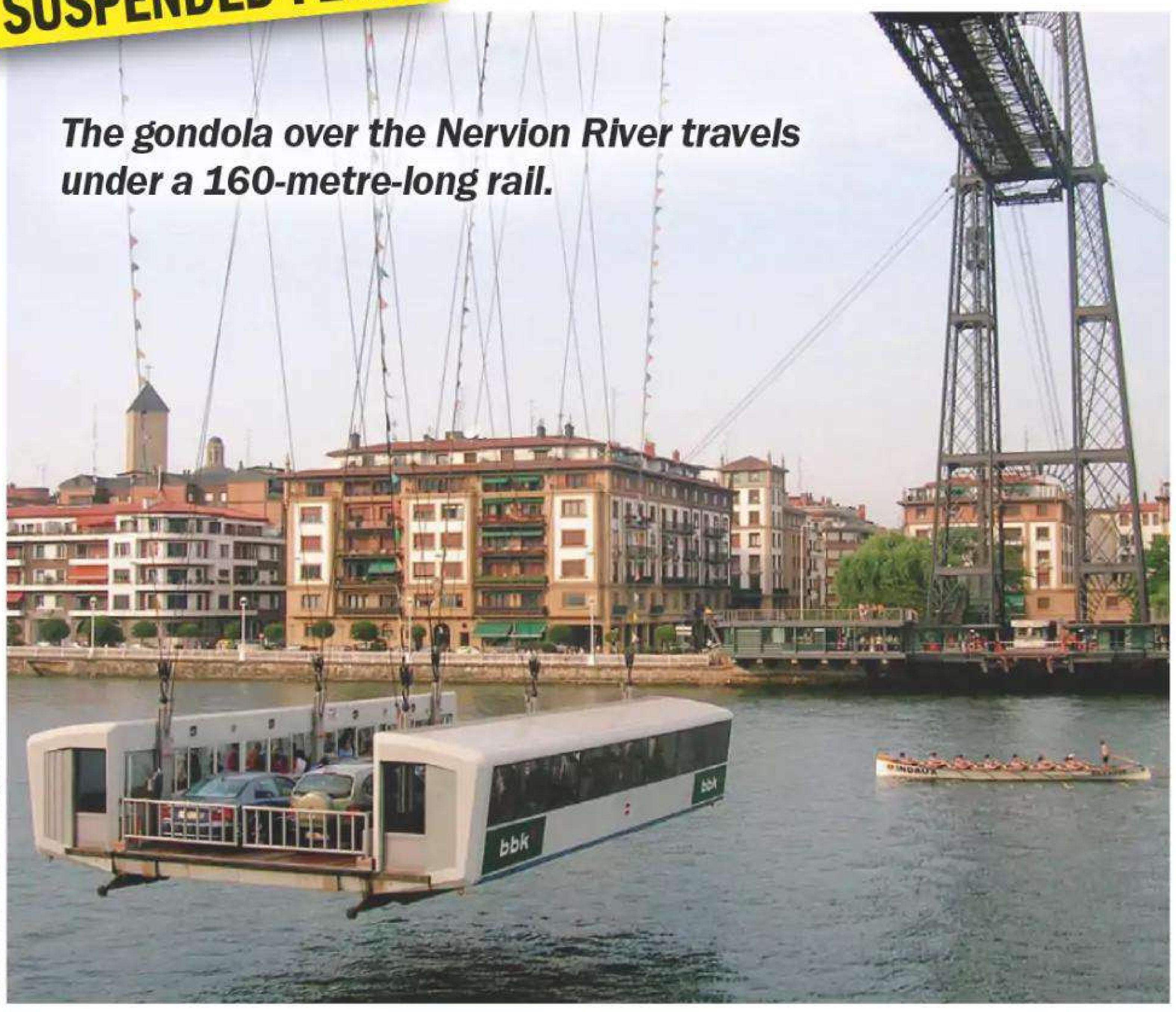
From the beginning, Eiffel was under immense time pressure to complete the tower in the spring of 1889, when the city would mark the centenary of the French Revolution and host the World Fair. With only one fatal accident, 3,000 workers managed to assemble 18,038 prefabricated elements using 2.5 million rivets.

When it was inaugurated on 31st March 1889, the 300-metre-high and 7,300-tonne tower was the tallest building in the world. The 7.7-million-franc price tag quickly paid for itself and the anger over the hideous "street lamp", as the tower was dubbed, died down.

The Eiffel Tower, built between 1887 and 1889, was originally planned to be removed after 20 years.

UNIVERSITÄTS UND LANDESBIBLIOTHEK DARMSTADT

SUSPENDED FERRY



The gondola over the Nervion River travels under a 160-metre-long rail.

JAVIER MEDIAVILLA EZQUIBELA

Fastest route between two areas of Bilbao separated by river

For centuries, the Nervion River had separated the two northern Spanish towns of Portugalete and Getxo. The wide river flows into Bilbao's busy harbour, so building a stone bridge was out of the question; it would block vital shipping traffic.

The solution was steel, but the bridge couldn't cost too much or take up much space, as the region was poor and densely built up. Neither a bascule bridge, a swing bridge, a lift bridge nor a suspension bridge could be used. Therefore, Spanish engineer and architect Alberto de Palacio proposed a transporter bridge – a large gondola suspended under a steel skeleton.

Both towns were enthusiastic about the idea because it was cheap and wouldn't get in the way of ships. Work on the Vizcaya Bridge began in March 1890. Three years later, the bridge was completed, and the 10-metre-long gondola could be pulled across the river by a powerful steam engine for the first time.

19,200 TONNES OF STEEL

Wuppertal's suspension railway

From 1826, industrialists in the German Ruhr region wanted a railway to transport coal from the mines to the area's steelworks. The dream was to build an elevated railway that wouldn't get in the way of other traffic.

It wasn't until 1887 that the idea was taken up by the city council of Wuppertal. The city was in a narrow valley, and the only free space for a short-line railway was over the Wupper River, which runs through the city. But the plan met with fierce opposition from Christian groups. They believed it was sinful to challenge God's order by building a railway 12 metres in the air. "Anyone who rides this satanic railway will face God's punishment!" they proclaimed. The protests delayed the project but couldn't prevent it.

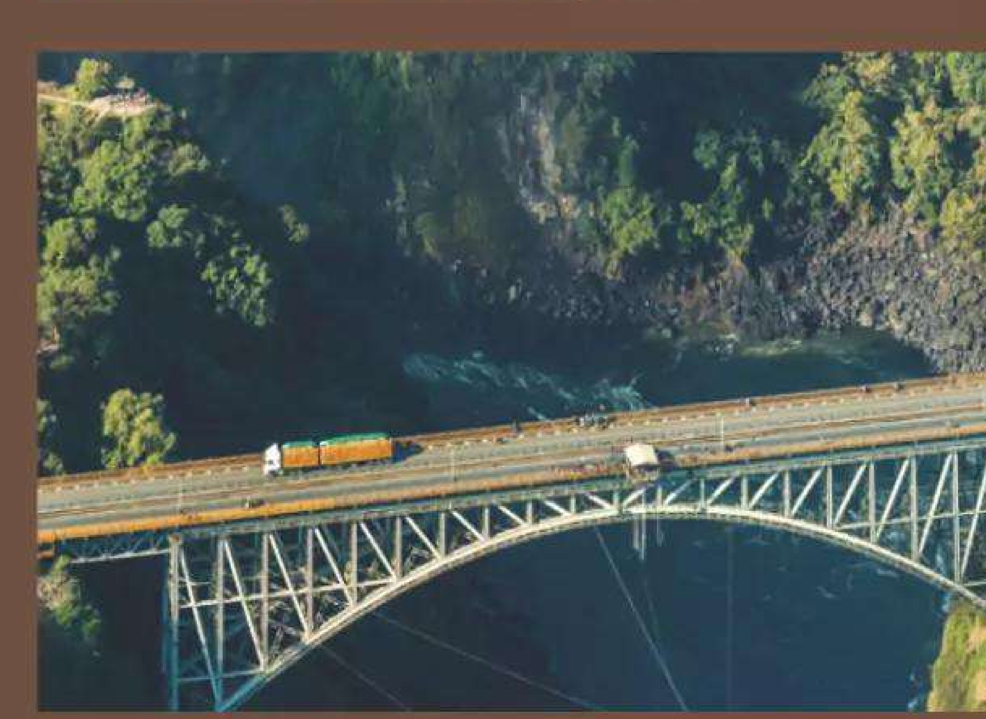
A total of 19,200 tonnes of steel were used before the Wuppertaler *Schwebebahn* (Suspension Railway) was completed in 1901. The cable car was hailed a modern marvel and passengers flocked to it. By 1925, the cable car had served its first 25 million travellers without incident.

130 METRES ACROSS RIVER

Victoria Falls Bridge would open Africa up

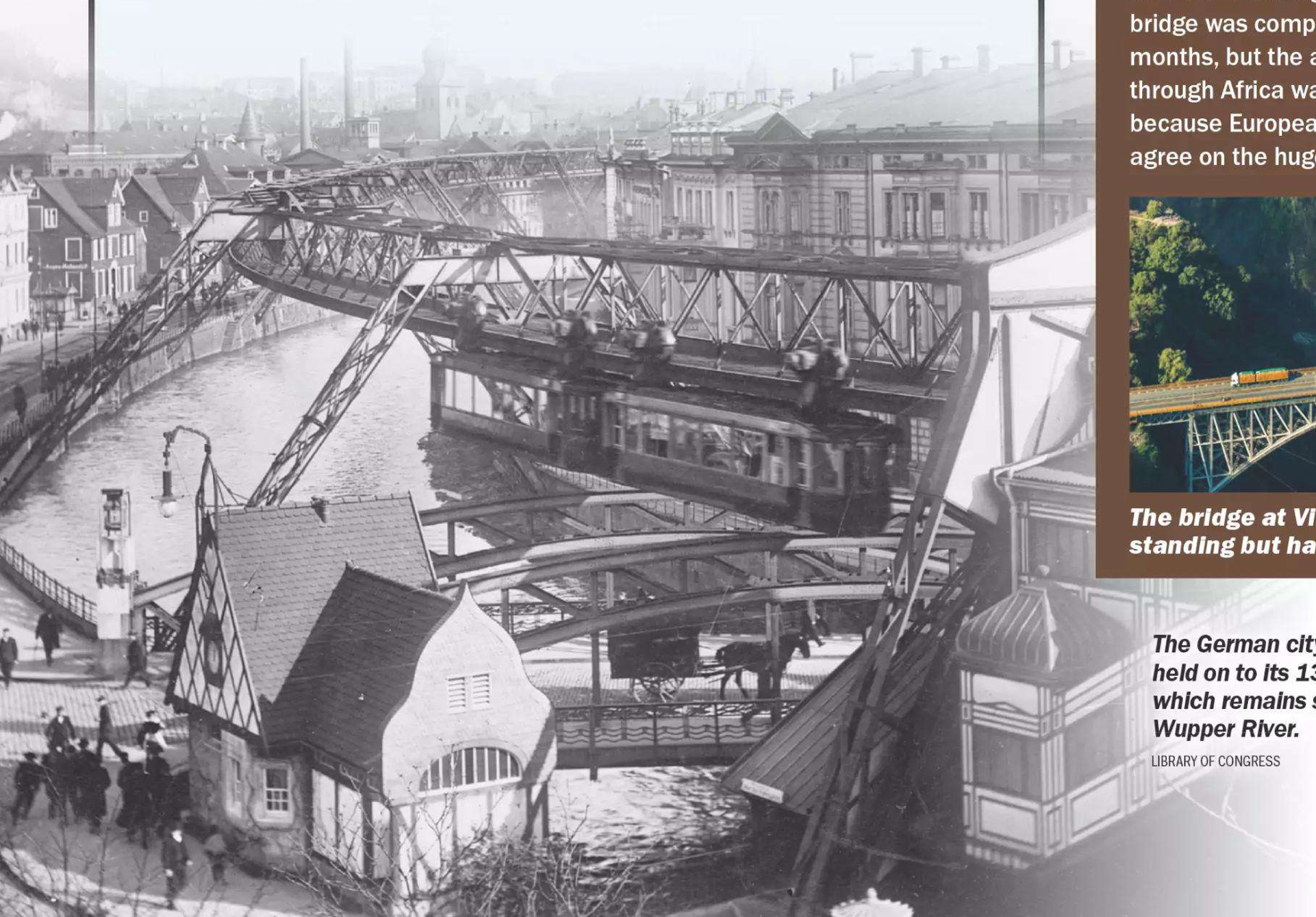
Africa's colonisation gave Europeans access to vast natural resources. The problem was getting the raw materials to the factories and consumers in Europe. Only a railway from south to north – from Cape Town in South Africa to Cairo in Egypt – could do the job.

The construction of the track presented many natural challenges. The biggest was a deep gorge at the Victoria Falls. After years of planning, work began in 1904 – 130 metres above the rushing Zambezi River. The bridge was completed after only 14 months, but the ambitious railway through Africa was never finished because European powers couldn't agree on the huge project.



The bridge at Victoria Falls is still standing but had little impact.

DIEGO DELSO/DELSO.PHOTO



The German city of Wuppertal has held on to its 13.3-kilometre track, which remains suspended over the Wupper River.

LIBRARY OF CONGRESS

WORLD'S TALLEST BUILDING

New York race to the top

Car magnate Walter Chrysler built the world's tallest building, but less than a year later his Chrysler Building stood in the shadow of the Empire State Building.

By the late 19th century, engineers had realised that steel wasn't just great for railways and bridges; it could also be used to build at height. A race to construct the tallest building began. In 1902, the world's first skyscraper with a steel frame was built in New York. It was the 87-metre-tall, triangular Fuller Building, quickly nicknamed the Flatiron Building after its shape.

But rich tycoons wanted to build much taller. So, when architect William Van Alen presented his plans for a futuristic 246-metre Art Deco skyscraper in 1926, the founder of the Chrysler car company jumped on board. However, Walter Chrysler insisted that the skyscraper should be 282 metres tall, making it the tallest in the world – and that the gargoyles should resemble Chrysler's winged radiator caps.

Construction began in 1928, and the load-bearing steel skeleton grew rapidly. On average, the Chrysler Building grew by four floors a week, and in just one year, the building's exterior was complete. It required 21,000 tonnes of steel and 400,000 rivets. It was then clad with 3.8 million bricks and 3,862 windows.

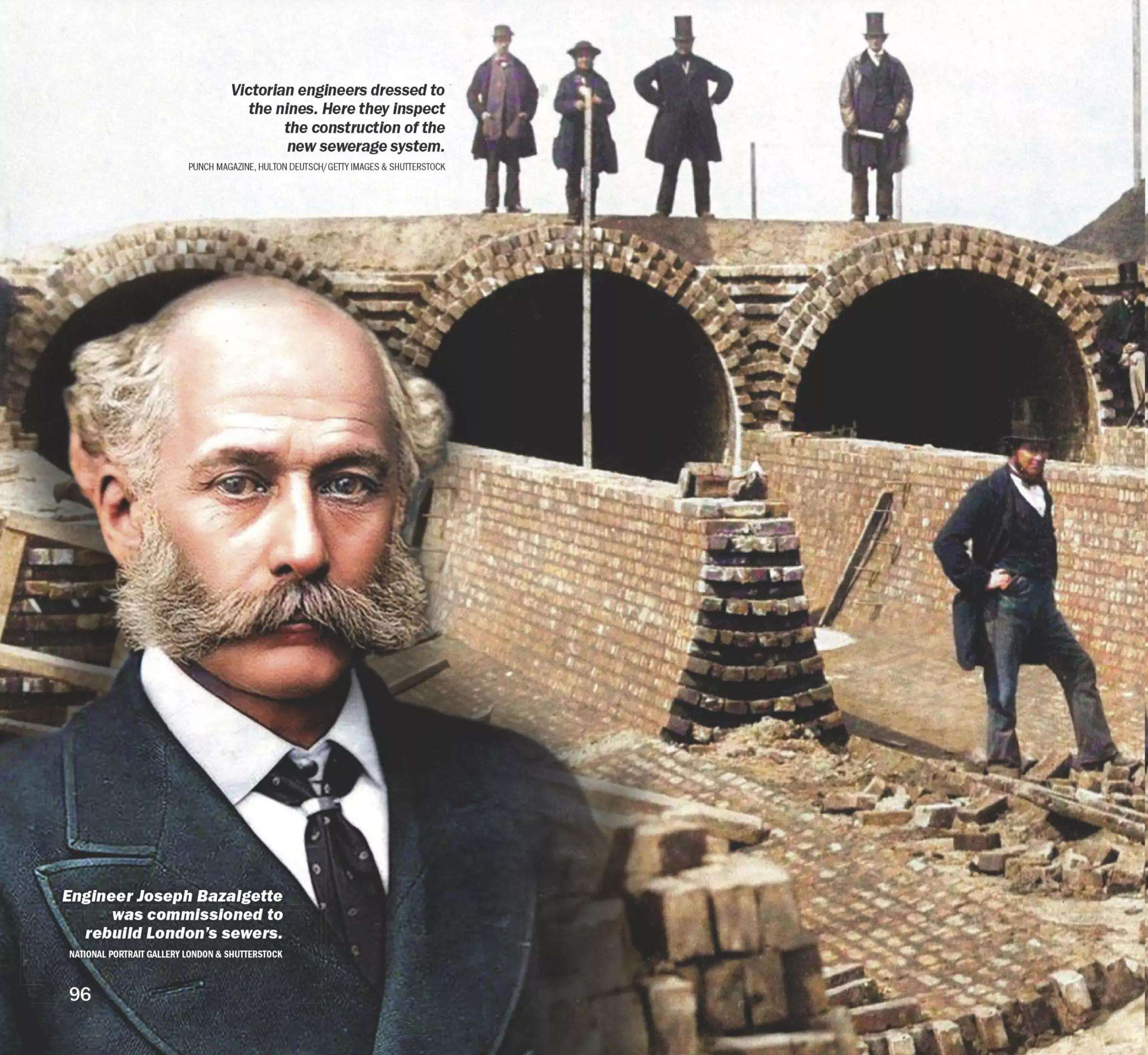
Including the antenna, the building was 319 metres high. Walter Chrysler could now boast of owning the world's tallest building, but his joy was short-lived. Less than a year later, the Empire State Building (381 metres) was completed.

The architect was inspired by Chrysler cars. For example, the upper floors are designed like the radiator of a Chrysler.

SAMUEL GOTTSCHO

PLUMBING

In 1858, the streets of London were flooded with sewage. The stench was unbearable and the drinking water poisoned. Yet no one listened to the engineer who had found the solution to the city's life-threatening problems.



Victorian engineers dressed to the nines. Here they inspect the construction of the new sewerage system.

PUNCH MAGAZINE, HULTON DEUTSCH/GETTY IMAGES & SHUTTERSTOCK

Engineer Joseph Bazalgette was commissioned to rebuild London's sewers.

NATIONAL PORTRAIT GALLERY LONDON & SHUTTERSTOCK

A satirical drawing from 1858 offers an imaginative take on the myriad organisms that could be found in a drop of polluted Thames water.
PUNCH MAGAZINE

JOB OF THE CENTURY

BY ANTJE GERD POULSEN

The sun was setting over the rooftops of London. It was summer 1858. The brown water of the Thames churned like a thick foamy soup around the pillars of Westminster Bridge. And the stench was more nauseating than ever.

Along the riverbank, where the stinking water turned into a thick sticky mass, ragged children rummaged with sticks in the mud to find nails, scraps of rope or bones to sell to rag-and-bone men. The brown gunk dried in the sun into a grey cake on their thin legs. They came here every day. The sludge of the sewer outlets was their livelihood and these wretched people who lived off the muck were at the bottom of society. This was Dickens's London. This was Victorian London. And the smell was London's Great Stink, as it was called in the increasingly irate newspaper articles demanding action.

30,000 died from cholera

The reek came from the bodily functions of over two million inhabitants. And from the effluent of livestock, slaughterhouses, tanneries and overcrowded cemeteries.

The waste flooded sewers and basements, contaminated water pumps and flowed into the river. The stench penetrated everywhere via windows, doors and cracks. Even through the brickwork of the Houses of Parliament, where the few remaining MPs pressed hand-embroidered handkerchiefs to their noses in a vain attempt to keep the smell out.

Many had long since packed their families and suitcases into horse-drawn carriages and travelled to the countryside. Away from the big city, known as a stronghold of civilisation, but now drowning in the faeces of its own population.

This didn't only happen that summer. It had also occurred over the previous few years and had been the subject of newspaper articles and numerous commissions. Cholera had struck three times since 1831, wiping out entire families in crowded poverty-stricken neighbourhoods in a matter of days. In total, cholera had claimed the lives of over 30,000 people.

Yet it was only now that the problem affected the noses of the distinguished MPs that something was being done. They finally decided that London needed a new sewerage system to divert the bacterial soup away from the city. And they gave the Metropolitan Board of Works the power and

Much of London's population in the late 19th century lived in slums, where cholera claimed most of its victims.

GRANGER/IMAGESELECT

The waste flooded sewers and basements, contaminated water pumps and flowed into the river.

money to get the job done. One man more than any other was relieved by this decision – the chief engineer of the Metropolitan Board, Joseph Bazalgette. He had been trying to get permission to do something about the looming environmental disaster for years.

Now he could finally undertake the large-scale engineering project that would prepare London for the future and save its citizens from an environmental disaster.

Poor wallowed in sludge

For centuries, London had been known for the quality of its drinking water. In the Middle Ages, there were so many salmon that apprentices asked their master craftsmen if they could only eat the fish a maximum of twice a week. But within a few years, the Thames became so polluted that for a stretch of four to five kilometres, it was completely devoid of life. The last salmon was caught in 1833.

And there were good explanations for this. First, the population had more than doubled in 50 years. Second, the flushing toilet had become a much sought-after success, and third, the city had abandoned its old sanitation system without establishing a new one.

Until 1815, human waste was collected in around 200,000 cesspits located all over the city, and for a fee, so-called nightmen emptied these latrine pits and transported their contents to the countryside. But the system couldn't cope with the rapidly growing population.

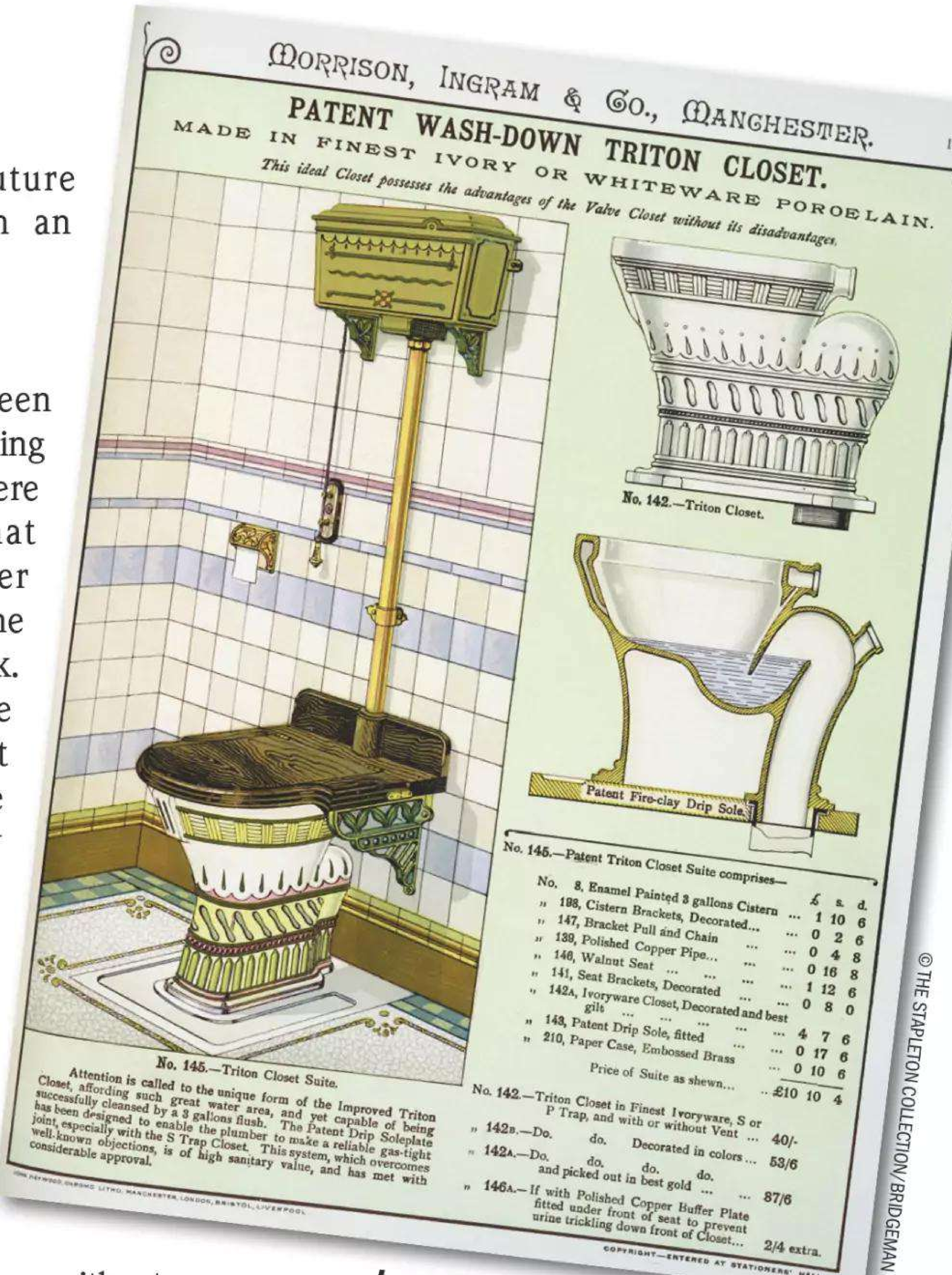
The cesspits overflowed and the nightmen raised their price because they had to go further and further outside the city to get rid of their foul cargo. London's poor couldn't pay, and the filth eventually piled up in basements, backyards and narrow alleyways. As a result, in 1815, the authorities lifted the ban on discharging household water and waste into the sewers.

Drinking water taken from Thames

Originally, the sewers were only built to carry surface water away from the city and into the river. But now they were opened to the daily discharges of over two million people. And Londoners found themselves in a sanitary death trap.

The state of the city was an open invitation for the cholera bacterium to strike. As the sewage washed cholera epidemics into the city, newspapers were flooded with articles about the miserable sanitary conditions and poor drinking water quality. But the two factors were never linked.

Charles Dickens was among those who publicly criticised the drinking water supply. He visited a London waterworks in 1850 and described how the tide could wash sewage back into the river at the very point where the waterworks drew up water for the city.



London's old sewerage system was only designed to carry away surface water. It didn't have the capacity to handle the discharge from the newly invented flushing toilets.

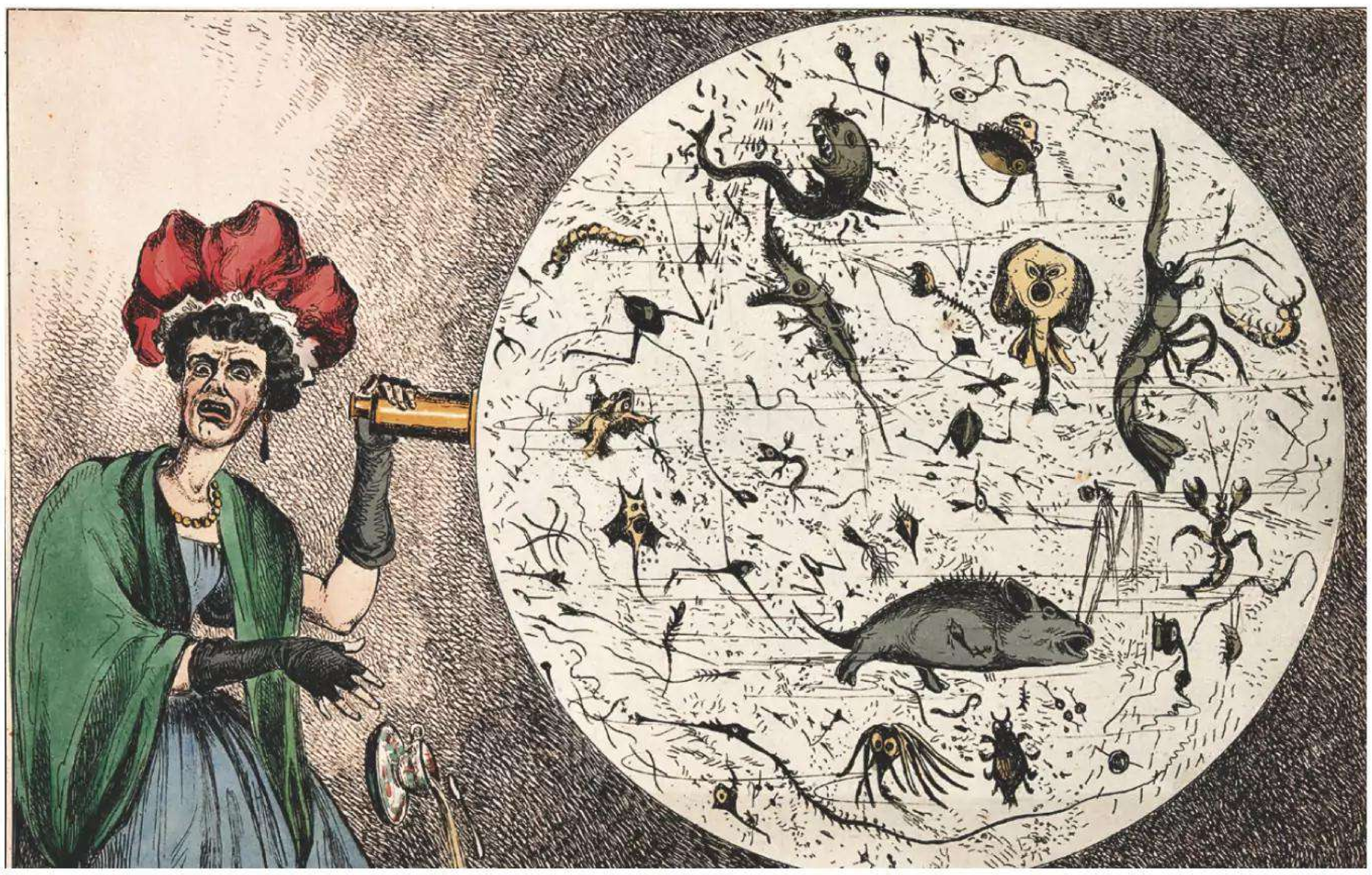
But it didn't help. Several commissions were set up over the years to deal with the problems, but they had neither the money nor the power to really do anything. And the resistance from the various local councils, waterworks and sewerage commissions in different neighbourhoods was strong. Every time someone spoke in favour of an overarching solution for the whole city, the debate about centralism versus local self-determination raged. And nothing was done.

It wasn't until 1856 that the city got its first proper city-wide council, the Metropolitan Board of Works. And it wasn't until the Great Stink that the board gained the power and means to act.

Cholera came from India

In the meantime, cholera was ravaging the poorest neighbourhoods.

It first arrived from India in 1831 and killed over 6,000 people in London. Abdominal pain, vomiting and diarrhoea announced cholera's hold on a victim. If a person was affected, it was often only 24 ►


WELLCOME LIBRARY, LONDON

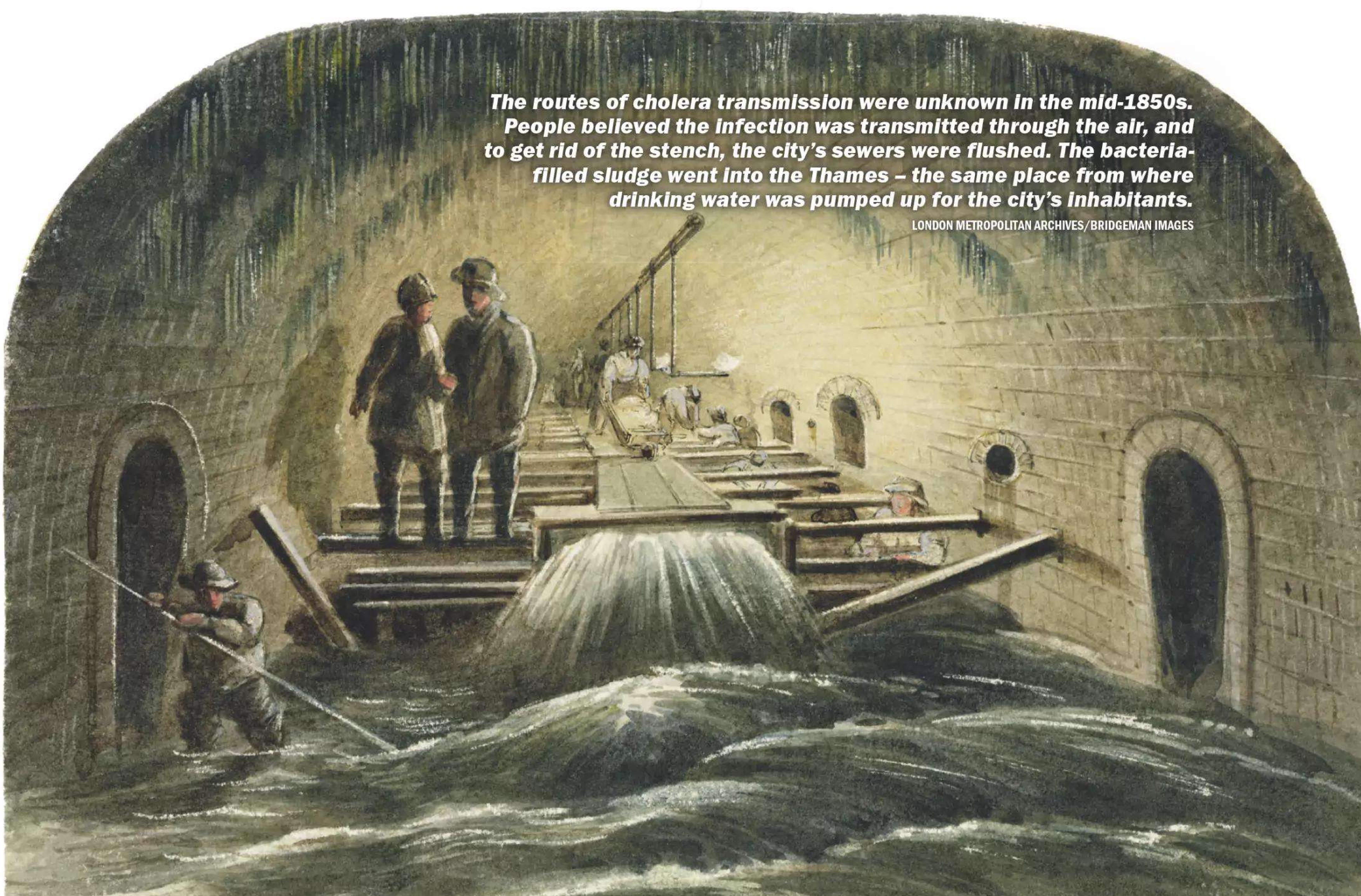
Newspapers did not mince their words in criticising the waterworks. This satirical drawing from 1858 was dubbed* Monster Soup *and supposedly depicted the water from the Thames.

▶ hours before they lay drained of fluid and life, their skin bluish-grey, waiting for the last strained heartbeat. That's how quickly cholera reaped its harvest. The poor could not afford funerals, so dead bodies lay for days among the living. Onions were peeled en masse to hide the smell of decomposition, and doctors were powerless. In the respected medical journal *The Lancet,* they wrote dejectedly: "We know nothing." But one doctor would not accept defeat: John Snow. He settled in Soho, one of the worst affected neighbourhoods, and set out to discover how cholera was transmitted.

Snow theorised that the disease came from the drinking water. But he was up against powerful forces. There was another theory about the infection that prevailed. The miasma theory, which dated back to the ancient Greek physician Hippocrates, had many followers. According to this hypothesis, the disease was in the air. And when the odour was at its worst, the risk of inhaling infectious agents was greatest, people believed. The stench was like an "angel of death" over London, it was reported.

It was primarily the lawyer Edwin Chadwick, a staunch advocate of social reform, who promoted the theory on a massive scale. Chadwick wrote in an article in *The Times* that "all smell is disease". Chadwick helped pave the way for a law in 1848 that made it compulsory to connect households to the sewerage system. But it only made matters worse. Even more sewage went into the Thames. And at the end of 1848, the second cholera epidemic began.

Chadwick, who had now become chairman of one of many sewerage commissions set up during that period, made another fatal decision. Again on the theory that the contagion was airborne. To get rid of the odour, he ordered all sewers to be flushed. Any old sludge that had accumulated in the city's sewers was now swilled out into the Thames, which thus



The routes of cholera transmission were unknown in the mid-1850s. People believed the infection was transmitted through the air, and to get rid of the stench, the city's sewers were flushed. The bacteria-filled sludge went into the Thames – the same place from where drinking water was pumped up for the city's inhabitants.

LONDON METROPOLITAN ARCHIVES/BRIDGEMAN IMAGES

By the end of 1849, 14,000 Londoners had died of cholera. And in 1853, the disease struck again.

received an even higher concentration of the deadly bacterial cocktail.

By the end of 1849, 14,000 Londoners had died of cholera. And in 1853, the disease struck again. This time it claimed over 10,000 lives.

Dr Snow found source of infection

In the meantime, John Snow had carried out extensive detective work. Like an alternative Sherlock Holmes, he had trodden the foggy alleys of the slums in his search for cholera. He visited tenements that were more like stables than homes, but where large families lived crammed into a single room. He noted where cholera had ravaged and who it had spared. He also noted where the residents got their water from. And discovered that those who fell ill got their water from contaminated sources.

In fact, Snow managed to prove his theory. But he couldn't get through to the authorities. In 1853 – the same year the third epidemic hit the city – his hypothesis was officially rejected despite thorough scientific work.

Another man who was concerned about sanitation and supported the contagious odour theory was engineer Joseph Bazalgette – the man who ended up being London's saviour.

Paradoxically, it was on the basis of an incorrect theory of contagion that he embarked on the mammoth engineering task of saving the city from cholera.

Engineer saved the city

For years, Londoners could see Joseph Bazalgette sailing the Thames or wandering around the London countryside with measuring instruments and a notepad. He had a plan. Using gravity and the tides, he would rid London of the Great Stink.

Below the city, the ground would be cut through by an entirely new sewer system built on three levels, with three main interceptor sewers on the north side of the Thames and two on the south side, which would absorb the huge volume of liquid from the existing sewer network. The main sewers would then discharge the sewage into the river at just the right time and ▶

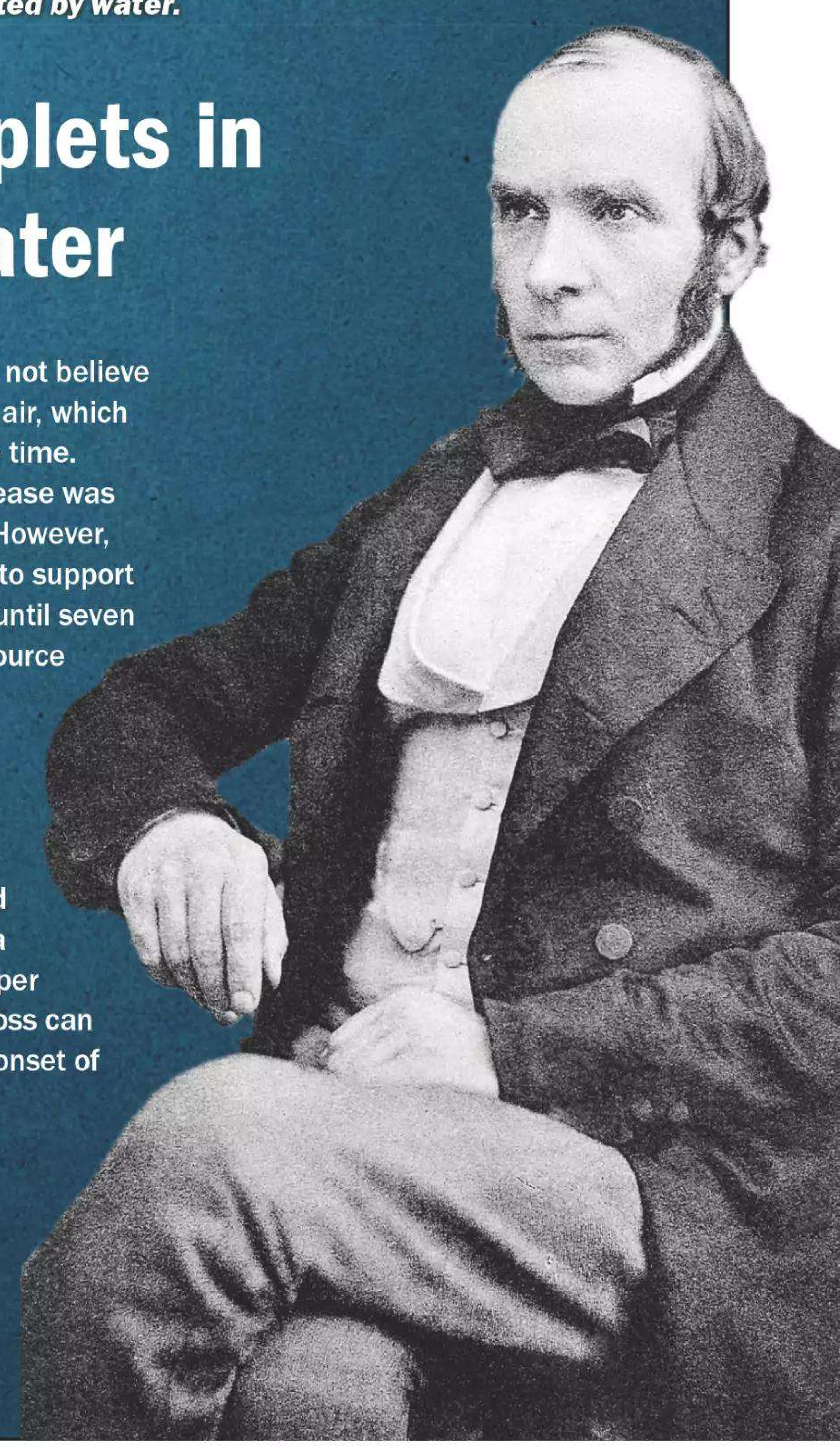
"Father Thames introducing his offspring to the fair city of London," read the text. The children were diphtheria, cholera and scrofula – diseases that were transmitted by water.

Deadly droplets in drinking water

The physician John Snow did not believe cholera was transmitted by air, which was the prevailing theory at the time.

Snow suspected that the disease was transmitted by drinking water. However, although he provided evidence to support his claim, it wasn't recognised until seven years after his death that the source of infection was a water pump and not the air.

When cholera bacteria enter the gut with drinking water, they can multiply and produce toxins. Within days, the infected person suffers severe diarrhoea and loses several litres of fluid per day. If left untreated, the fluid loss can be fatal within 24 hours of the onset of the disease.



John Snow located the centre of the cholera outbreak – a water pump on Broad Street. But his news fell on deaf ears.

▶ place for the tide to carry it all the way to the English Channel.

City became one big construction site

Joseph Bazalgette was a recognised engineer and his plan was the only serious proposal for a solution. Yet politicians rejected his idea. It took seven years and five revised plans before he was allowed to begin. But then he changed the city for ever. In addition to sewers and pumping stations, he also built major roads, parks and bridges. And he reclaimed 52 acres of marshland, the equivalent of 31 football pitches, where he built the huge Chelsea, Victoria and Albert Embankments with roads, pavements and parks, and underneath, in the cement, were sewers, underground railway lines and tunnels where electricity cables and gas and water pipes ran.

For Bazalgette, it was crucial that the sewers would future-proof London. They had to last far beyond his own lifetime. That's why he chose a relatively new material that would be particularly durable: Portland cement. But this fine and expensive cement had a serious flaw. If the mixing ratio was not exactly as prescribed, the cement was not the most durable material, but rather one of the most porous. However, Bazalgette solved that problem, too. He invented quality control – long before it became a concept. For each mix, the cement had to be tested to ensure that not a single centimetre of the over 600 km of main sewer pipes could crumble.

Residents could breathe again

When work began on the sewers in 1859, the people of London were excited. Finally, something was being done. The city was transformed into a huge construction site. Entire shanty towns sprang up where the main sewer lines went underground. The idea was that the main sewers would use the slope of the landscape and take advantage of gravity to speed up the movement of sewage.

But the centre of London was very low-lying, so the sewage had to be collected at pumping stations, where it was pumped up and stored until the tide came in, so it could be discharged into the water.

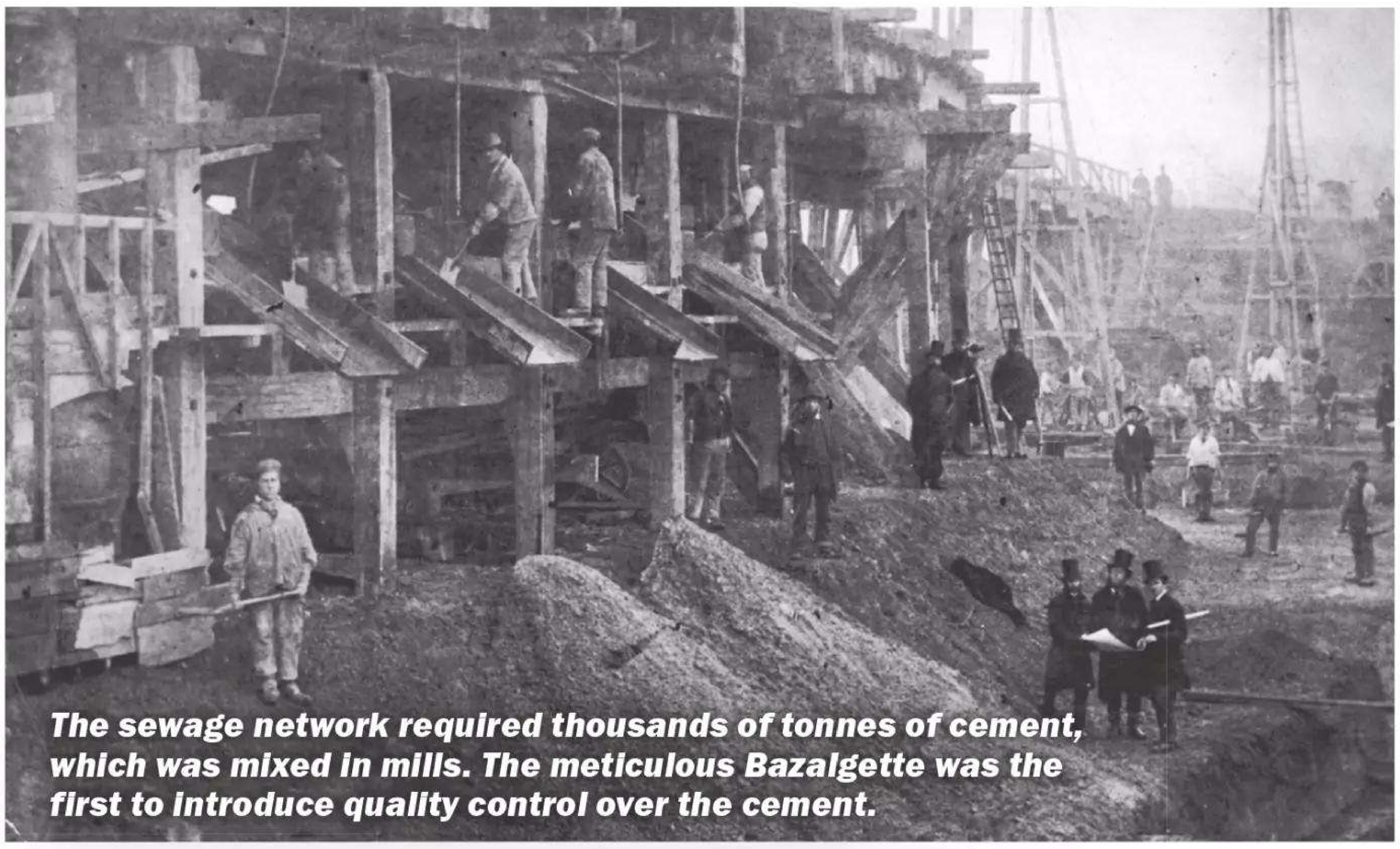
It was six years before the first pumping station could be inaugurated. And along the way, Joseph Bazalgette's project was hit by mishaps. Although he had fewer than 10 accidents in total during the entire period, he was severely criticised when six workers were buried alive in a landslide.

All the more joy and relief when, in 1865, the Prince of Wales could start up the enormous pumps at Crossness Pumping Station. But the joy was short-lived. Three months later, cholera broke out again. London was shaken. The smell was gone, yet cholera was still rampant.

However, it was limited to an area where the sewers were not connected to the new mains. And it proved Dr John Snow right – the infection could be traced to a single water pump. Bazalgette and many others realised that they were wrong, but Snow failed to gain recognition for his theory. By then, he'd been dead for seven years.

The last pumping station, Abbey Mills, was inaugurated in 1868, and both odour and infection were eliminated from the city. In 1892, Hamburg was struck by cholera, and the people of London were anxious to see whether they would escape. They did.

Thanks to Joseph Bazalgette's engineering feat, London has never since been haunted by the angel of death. ■



The sewage network required thousands of tonnes of cement, which was mixed in mills. The meticulous Bazalgette was the first to introduce quality control over the cement.

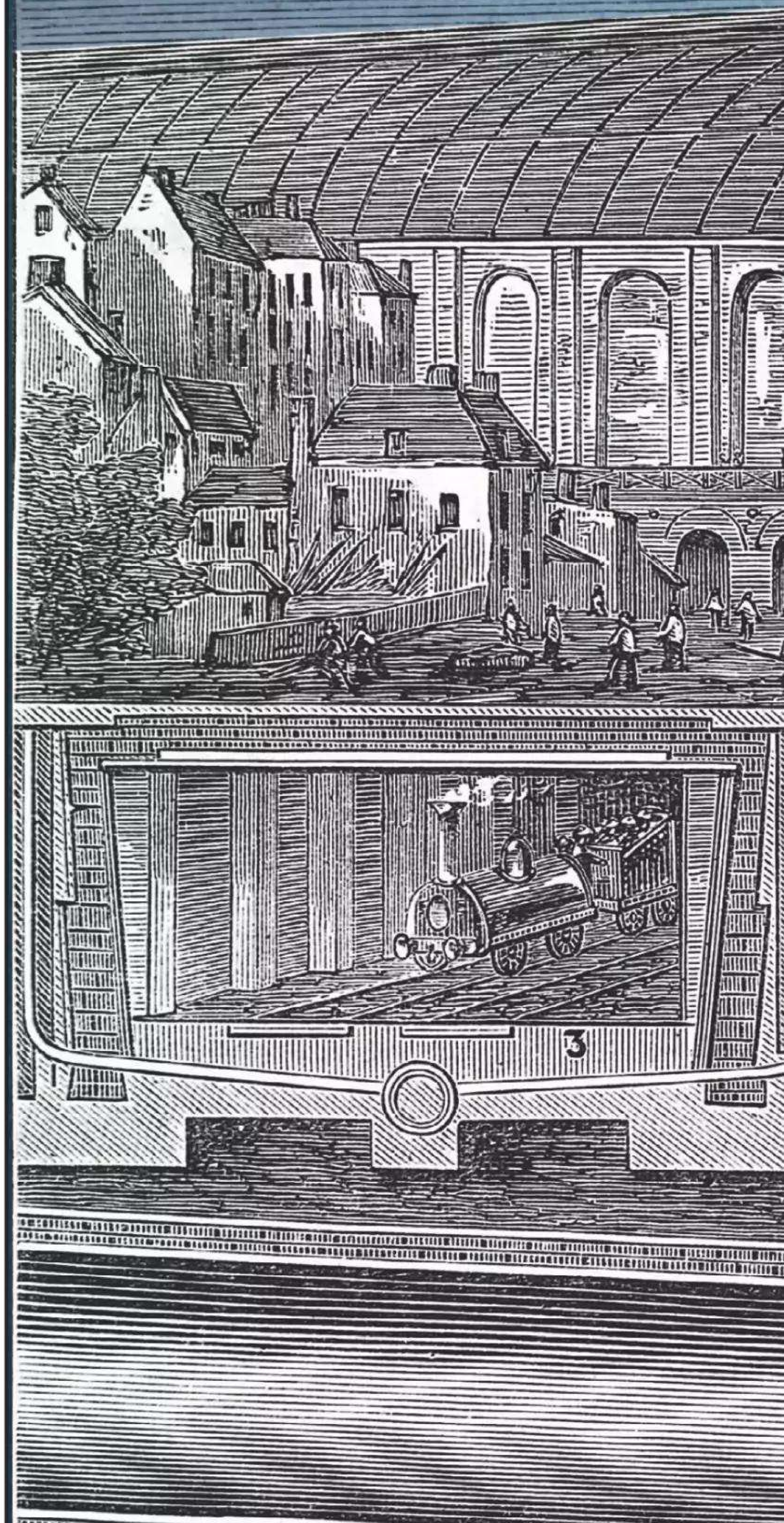
OTTO HERSCHAN COLLECTION/GETTY IMAGES

London got 850 km of sewers

The sewerisation of London was an enormous construction project. Workers built 130 kilometres of three-metre-high underground sewer tunnels to receive wastewater from another 724 km of newly constructed main sewers (see map).

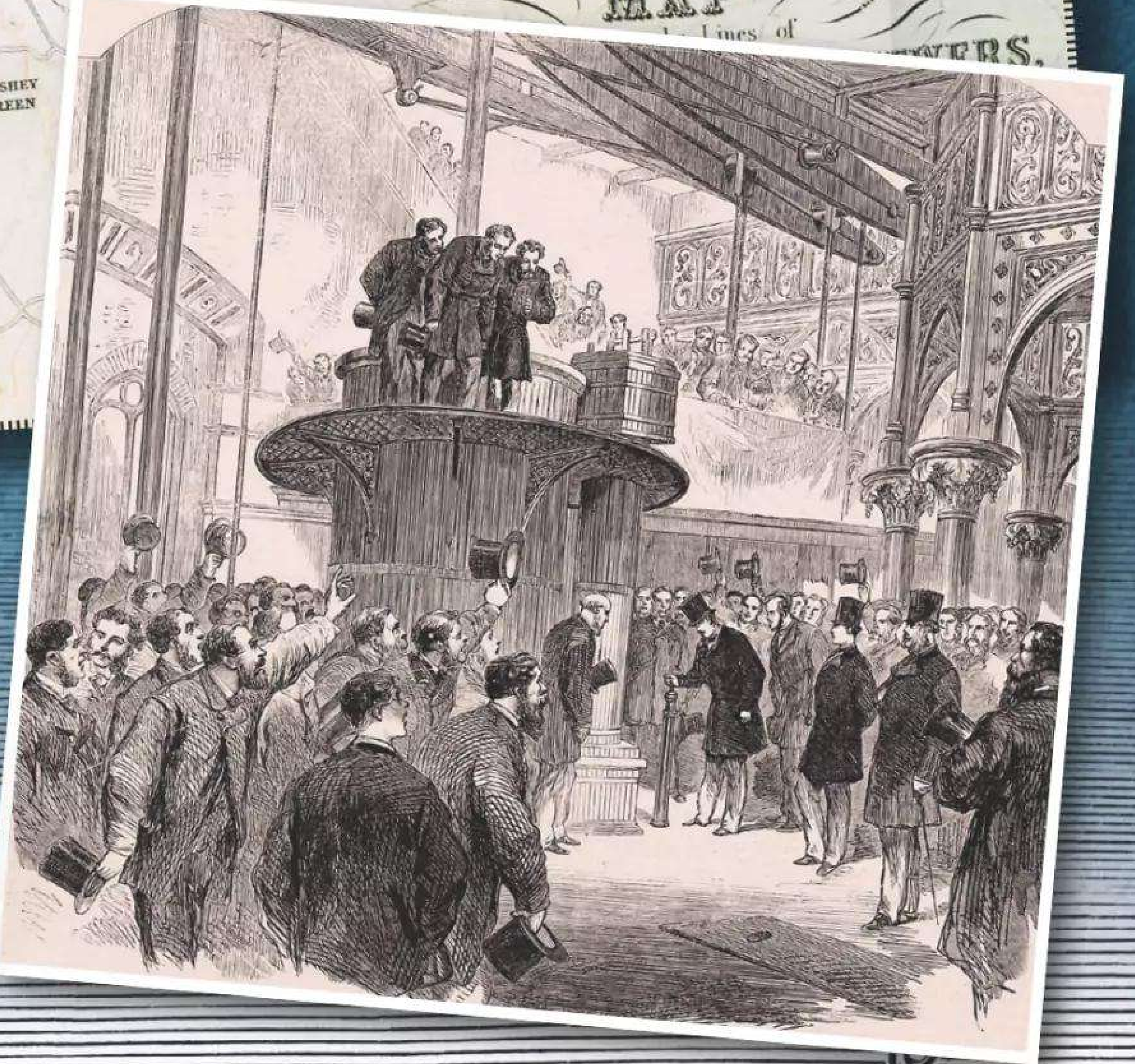
The new sewers absorbed wastewater from a network of existing sewer systems. The sewer network was built in three levels to ensure the right gradient. The northern sewer line alone, which was the highest in the landscape, required 40 million bricks.

At the same time, an area equivalent to over 30 football pitches was reclaimed next to the Thames to make way for the Victoria, Albert and Chelsea Embankments.

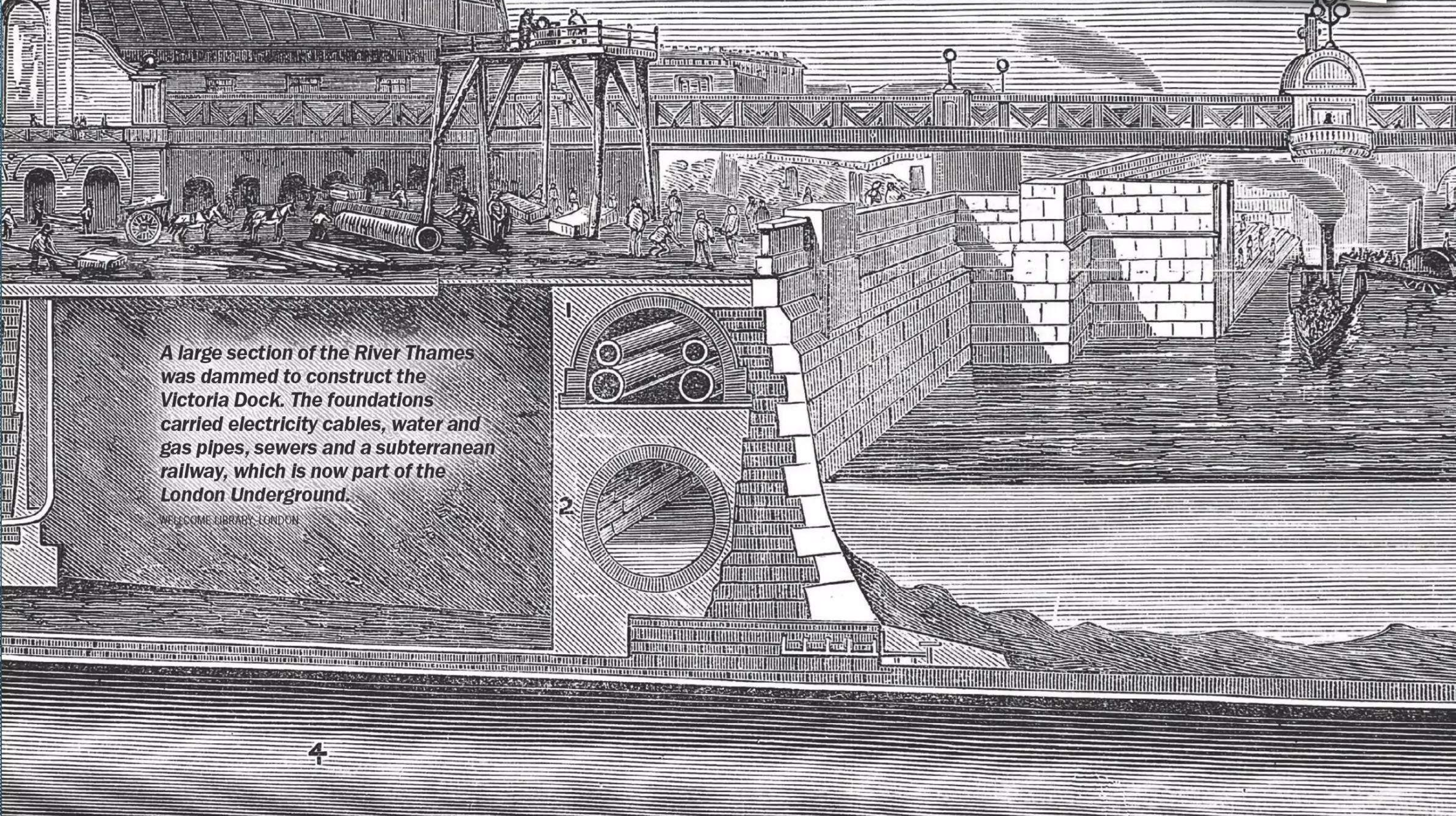


In 1868, London got an extensive network of new sewers.

© LONDON METROPOLITAN ARCHIVES/ BRIDGEMAN IMAGES


In 1868, the Prince of Wales started up the large pumps at the Crossness Pumping Station.

THE ILLUSTRATED LONDON NEWS



A large section of the River Thames was dammed to construct the Victoria Dock. The foundations carried electricity cables, water and gas pipes, sewers and a subterranean railway, which is now part of the London Underground.

WELLCOME LIBRARY, LONDON

Up to 5,000 labourers toiled around the clock to complete the dam in five years.

GETTY IMAGES & SHUTTERSTOCK

USA/1931

The population and agriculture in the western United States were growing rapidly, but the barren steppe states had far from adequate electricity and water supplies. A gigantic dam and hydroelectric power plant would solve the problem.

WORLD'S LARGEST BLOCK OF CONCRETE

During the economic crisis of 1931, thousands of unemployed Americans flocked to the Colorado River in the USA. Every day, they laboured on precarious scaffolding and in gas-filled shafts to build the world's largest dam. After five years of hard work, construction was complete and the 221-metre-high Hoover Dam rose up in the middle of the rushing river.

BY KASPER SCHLIE

SUN FILE PHOTO

On 18th April 1931, Six Companies signed the government contract to build Hoover Dam.

Dozens of excited spectators had gathered along the edge of the Black Canyon on 13th November 1932. They had come to see man tame nature. Over the coming hours, workers would force the mighty Colorado River out of its bed and into four diversionary tunnels. The goal was to create a site to build the mighty Hoover Dam on the riverbed.

It seemed an impossible task because around 20,000 litres of muddy water rushed past, at the bottom of the cliffs, every second.

One hundred lorries stood by, idling their engines. Each carried 12 tonnes of rocks and gravel to pour into the water. The aim was to form a temporary barrier north of the future dam.

At 11.30, the construction manager, Frank Crowe, signalled to his men. Moments later, explosions erupted from the canyon, where 3,500 pieces of dynamite had been drilled into the towering rock faces.

The water was whipped up as it was hit by thousands of rocks. The first lorry roared out on to a temporary bridge and tipped its load into the rushing river. Immediately, it returned to pick up another load. Every 15 seconds, a lorry emptied its load, and this continued for hours without the river moving an inch. It was not until 19.00 that the now 22,500 tonnes of rock stopped the foaming water, which was forced up towards the first tunnel. The water disappeared into the darkness and gushed out again 400 metres further on.

"She's taking it, boys, she's taking it," shouted a worker, his voice echoing between the rock faces.

He had just helped drain the construction site where the world's

Dam tamed the Colorado River

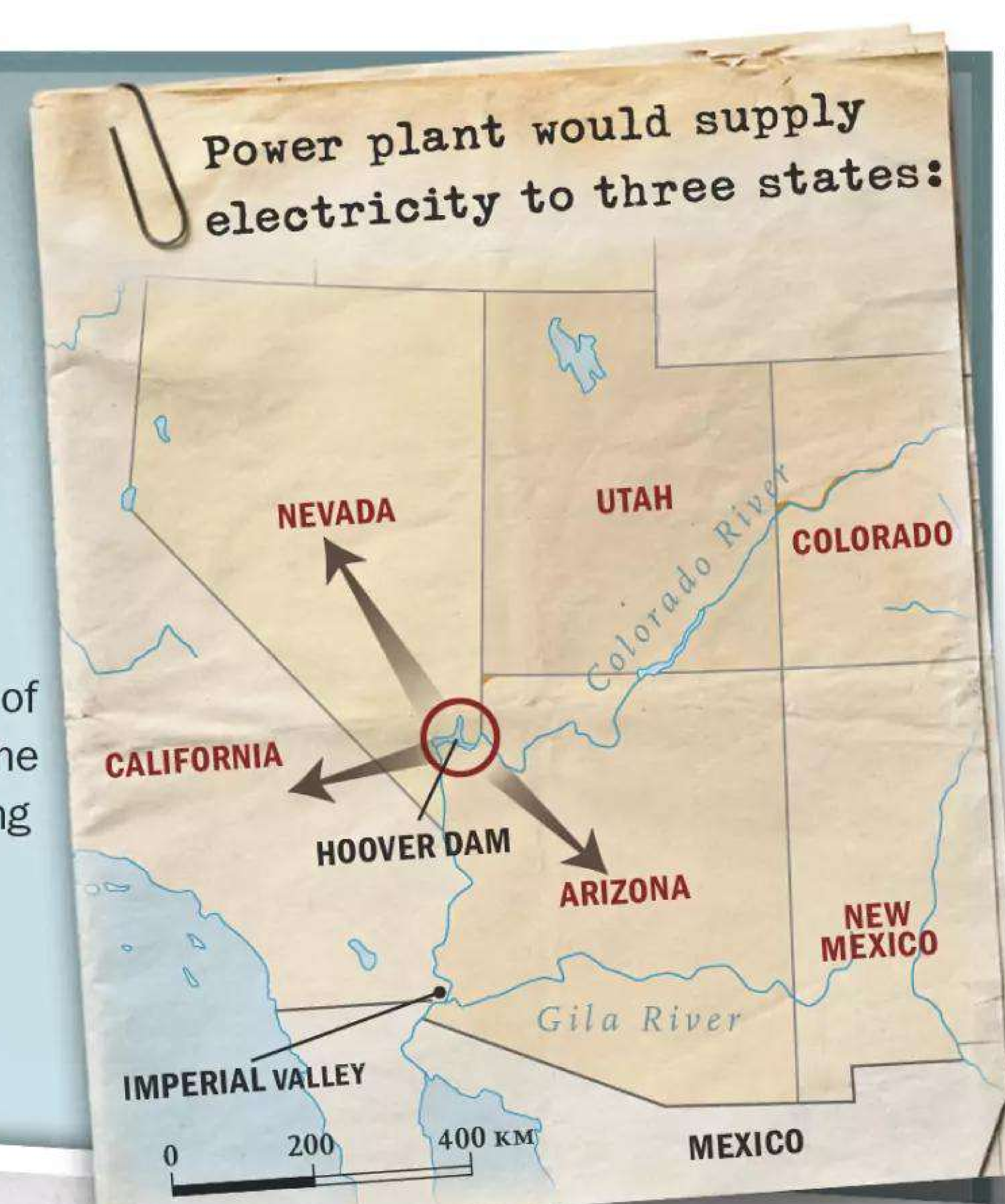
Flooding problems along the Colorado River prompted US authorities to build the world's largest dam.

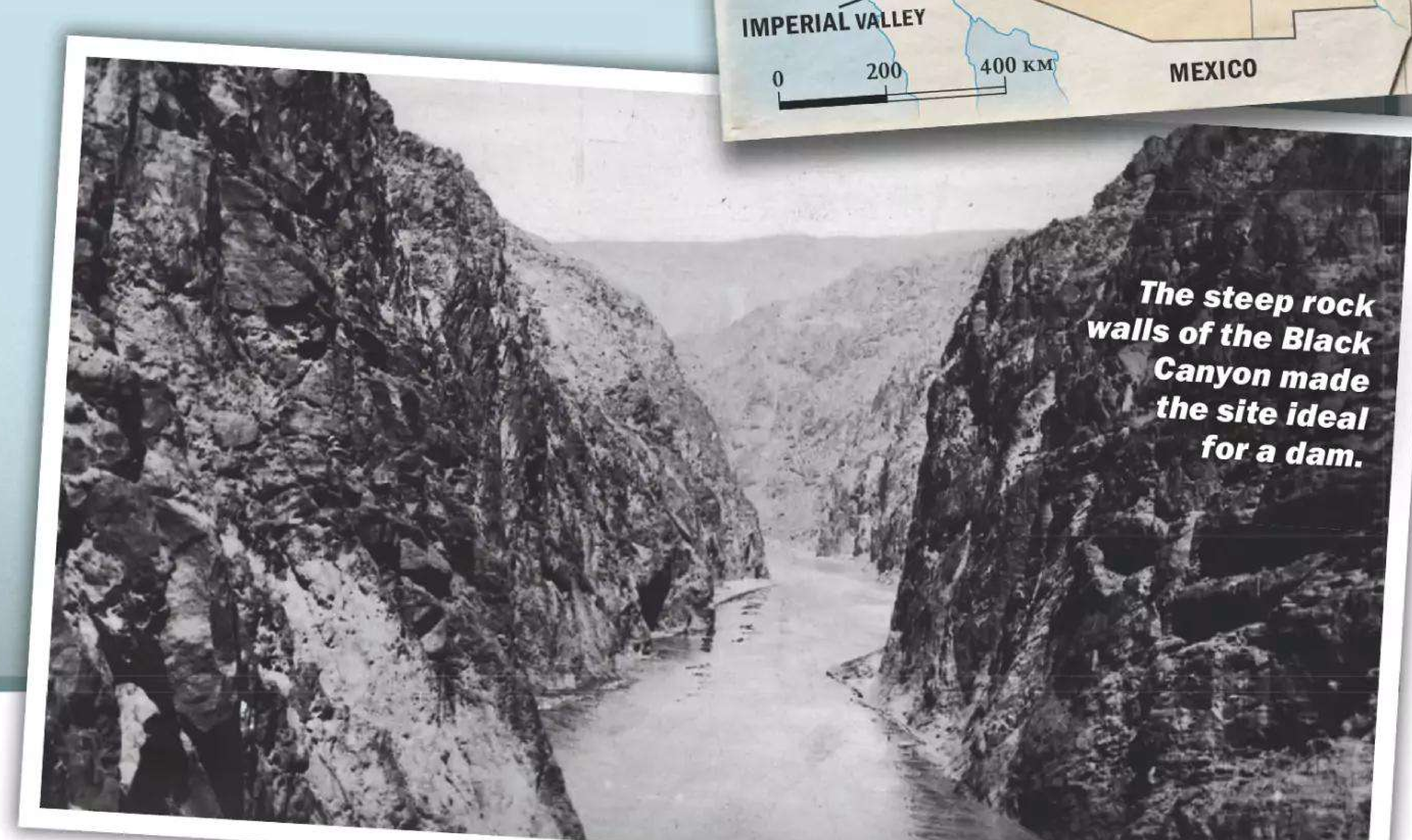
In 1869, an American major travelled all the way down the Colorado River in his rowing boat without encountering a single dam. The rushing river provided water for fields in the western United States, but regularly overflowed its banks.

The floods destroyed fields and claimed lives in California's Imperial Valley, through which the river meandered. In the 1920s, the US water authorities decided to put a stop to this. With the construction of the giant Hoover Dam – and several other dams that followed – the river was tamed. Today, the same authorities proudly call the Colorado River the most controlled river in the world.

The many dams, however, created new problems. In the 1920s, experts believed that more water was flowing in the river than there really was. As a result, the region's states were allocated excessive water quotas, resulting in only 9 per cent of the river's water reaching Mexico. While the dam therefore put an end to major flooding in the Imperial Valley, it also meant that Mexican farmers could no longer extract enough water from the river.

GETTY IMAGES & SHUTTERSTOCK





The steep rock walls of the Black Canyon made the site ideal for a dam.

largest dam would soon be built by 5,000 workers. The construction manager, Crowe, had every right to be pleased with himself. He'd only been on the job for 22 months and the entire project was already a year ahead of schedule.

The 221-metre-high Hoover Dam would be one of the largest construction projects of the 20th century. Up to six million tonnes of concrete would be used to erect the enormous structure that would stand in the middle of the raging Colorado River.

Never before had anyone attempted to build a dam of this size, and experts doubted whether it was even possible. However, the Six Companies consortium was determined. Not only did it want to build the dam, but it wanted to prove its mettle by delivering it to the government under budget and ahead of schedule.

Disaster expedited project

The people of the western United States had long dreamed of taming the 2,334-kilometre-long Colorado River. Rapidly growing cities such as Las Vegas, Los Angeles and San Francisco desperately needed more power – something that a massive hydroelectric power plant on the river could produce. At the same time, farmers along the river's banks wanted reliable access to irrigation channels and drinking water.

If the river could be tamed, people hoped it would also alleviate another problem – the fact that it often overflowed its banks and caused devastation.

Throughout the 1920s, the six states along the river's course argued with each other and the government about the exact distribution of water and power. Construction was constantly postponed – until a terrible event hastened the project. In 1927, 246 people died when the Mississippi River burst its banks. The disaster was so bad, and the need for more power so great, that in 1929 President Hoover made a decision: a new dam, with the working title Boulder Dam, was to be built in the Black Canyon, 40 kilometres from Las Vegas.

It would be placed between the cliffs of the canyon, creating a huge lake in the area behind the dam. The president's engineers warned that the project should be carried out according to "ultra-conservative" specifications – because if the dam collapsed, floodwater would kill huge numbers on its way to the Pacific.

The undertaking was so enormous that construction companies across the US had to join forces to raise enough capital to bid for the job. The winner was the so-called Six Companies, with which experienced construction manager Frank Crowe beat the competition in 1931 with a bid of around $49 million.

But not only did the government want a cheap dam, it also wanted it built quickly. Seven years was the maximum it could take, unless Six Companies wanted daily fines of $3,000. A deadline that was unrealistic, according to one of the US government's own economic consultants.

Frank Crowe wasn't intimidated, though: "I had spent my life in the river bottoms and Boulder meant a wonderful climax. I was wild to build this dam," he later said.

Unemployed flocked to Nevada

Fortunately for Crowe, the Depression had hit the US – and thousands of unemployed welcomed the prospect of years of well-paid work in the Nevada desert. Before Six Companies even had time to establish its headquarters above Black Canyon, scores of hopeful families flocked to the area in beat-up cars, on foot and even in horse-drawn wagons.

In the spring of 1931, hundreds gathered in a squalid camp on the banks of the Colorado River, which was quickly dubbed Ragtown.

One of the families who tried their luck was Tom and Erma Godbey with their four young children. "It looked like any place that is just built out of pasteboard cartons or anything else," said Erma. "Everybody had come in just a car with no furniture or anything."

Tom Godbey was a former miner who, in desperation, had lashed his family's belongings to the roof of their old Dodge and headed for Nevada.

However, conditions in the shantytown soon proved unbearable. Every day, the temperature rose to over 40°C, causing rubbish and faeces to stink, and attracting rats between the slum dwellings. At night, people wrapped themselves in wet sheets so they could sleep in the heat.

Workers flocked to the boss

One bright spot for the migrant workers was when Frank Crowe stopped by Ragtown to inspect the construction site. Someone shouted, "The big boss is here!" and thousands flocked over. "How many men you gonna need?", "I'll work hard chief!", "We ain't had much to eat lately. Please mister…" came the calls from the crowd, and Crowe could pick and choose.

For now, however, there was only work for a few hundred people – ▶

SHUTTERSTOCK

Huge project had to keep costs down

One consultant had no doubt when he heard the government's plans to build Hoover Dam in the middle of a desert with no infrastructure: "I consider it almost impossible to build." Frank Crowe of Six Companies disagreed. He did the maths and in 1931 was able to put the lowest price on the table:

Government requirements:
- **The dam must be completed after a maximum of seven years of work.**
- **All bidders for the contract must be able to provide a $2,000,000* security bond.**

**Approximately $25 million today.*

FRANK CROWE

The construction manager planned to save large sums of money by building Hoover Dam in five years instead of seven.

CREATIVE COMMONS & SHUTTERSTOCK

Built in record time

"We had 5,000 men in a 4,000-foot canyon. The problem … was to set up the right sequence of jobs so [the workers] wouldn't kill each other off." So said construction manager Frank Crowe, who organised and trained his workers so well that the dam was completed two years ahead of schedule.

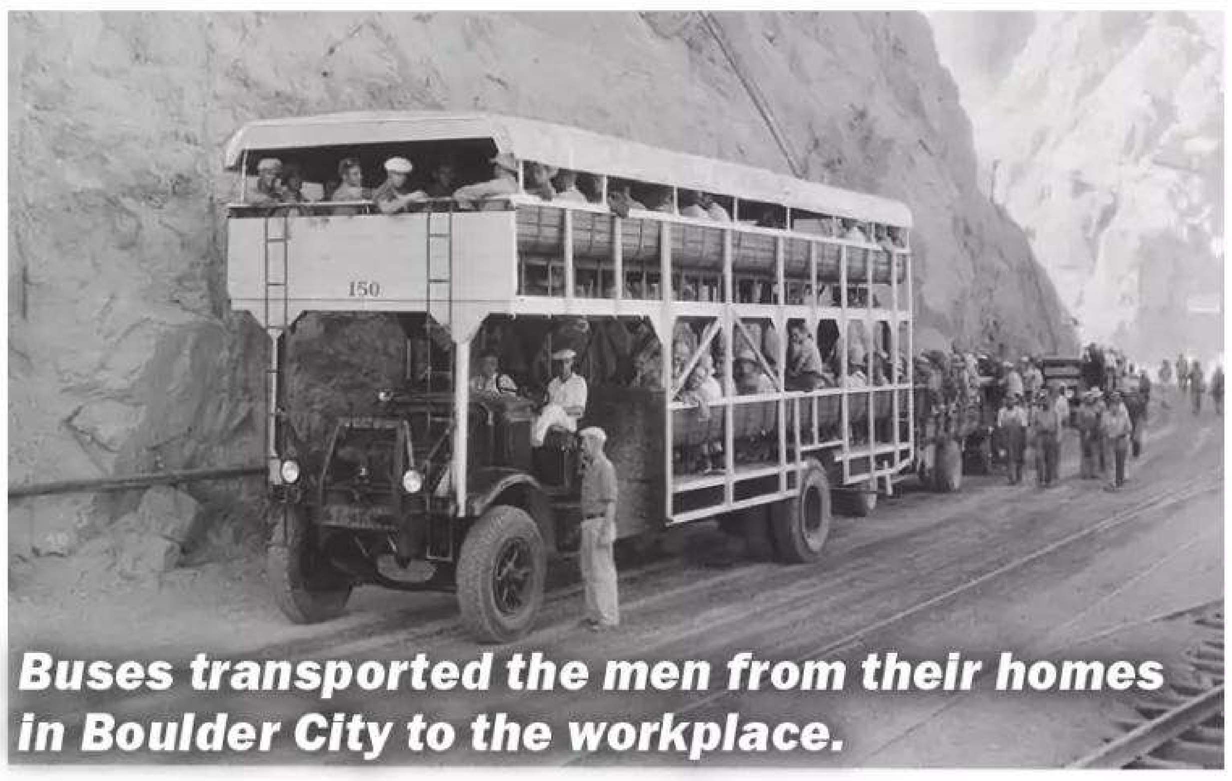
CLAUS LUNAU/HISTORIE

JANUARY-MAY 1931

1 Connecting Black Canyon to the outside world

Before the dam work can begin, the site infrastructure must be in place. That's why workers are building roads and railway tracks, and running high-voltage power lines. Everything runs through the new workers' town, Boulder City, and on to Black Canyon.

- 8 km of new road
- 50 km of railway
- 428 km of power lines



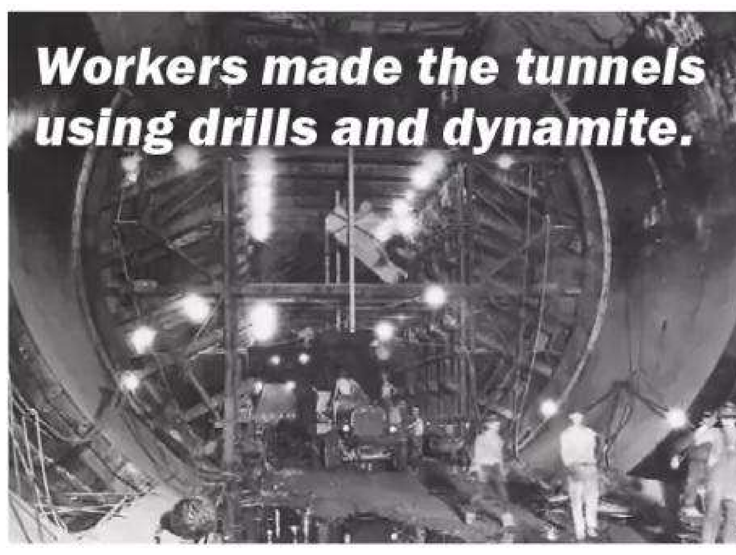
Buses transported the men from their homes in Boulder City to the workplace.

RSVLTS.COM

MAY 1931-NOVEMBER 1932

2 Tunnels are blasted into the canyon walls

Once the infrastructure is in place, the first 1,400 workers are hired. They start excavating four tunnels – two in Nevada and two in Arizona. They will divert the river so the dam can be built on a dry riverbed. The tunnels are around 1,300 metres long and 17 metres in diameter.



Workers made the tunnels using drills and dynamite.

RSVLTS.COM

including Tom Godbey. Before work on the dam could begin, the infrastructure had to be set up. The new employees built roads, a railway and power lines.

Heatwave led to deaths

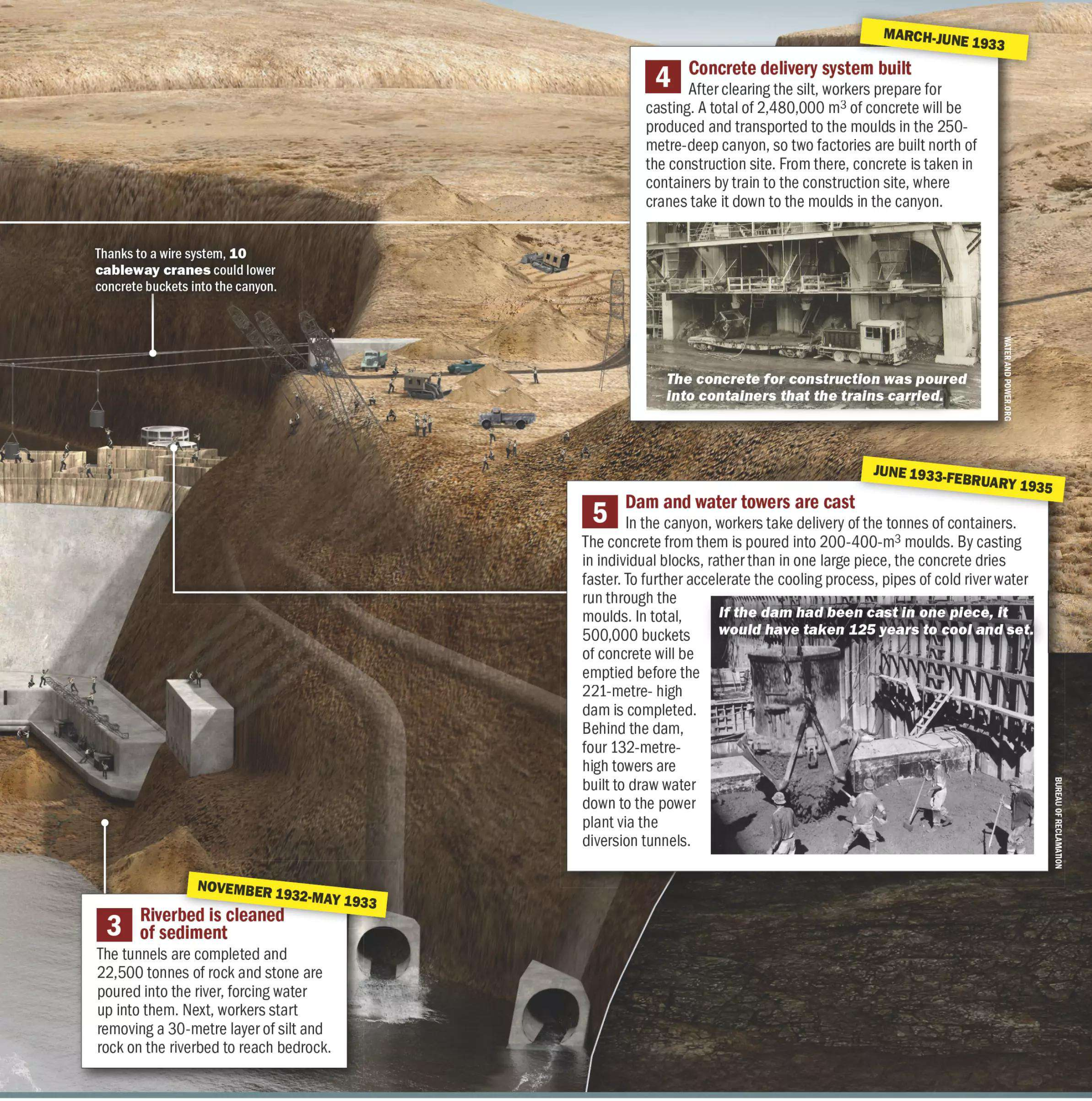
In May 1931, Frank Crowe and Six Companies finally began the first major phase of the project. Four tunnels were to be blasted through the rock and used to redirect the water so the dam could be built on a dry riverbed; 1,200 workers were hired to drill and blast their way through a total of 5,200 metres of rock, day and night. Unfortunately, a heatwave almost stopped the work before it started.

In July, the thermometer reached 48°C in the shade, causing workers to collapse from heat stroke. Eyewitness John Gieck was furious: "[They] arrived in Las Vegas dead, bloated and looking like they had been parboiled," he said.

Two months into the tunnelling, as many as 14 had died of heat stroke. "Six Companies threaten workers' lives!" read the trade union newspaper *Industrial Solidarity* – and it had a point.

Frank Crowe quickly earned the nickname Hurry Up as he appeared at all hours on scaffolding, in tunnels and even in canteens to speed up work – regardless of the temperature.

Everything had to be done as quickly and cheaply as possible. During the first few months, workers died in avoidable falls and blasting accidents. Even the



NOVEMBER 1932-MAY 1933

3 Riverbed is cleaned of sediment

The tunnels are completed and 22,500 tonnes of rock and stone are poured into the river, forcing water up into them. Next, workers start removing a 30-metre layer of silt and rock on the riverbed to reach bedrock.

MARCH-JUNE 1933

4 Concrete delivery system built

After clearing the silt, workers prepare for casting. A total of 2,480,000 m^3 of concrete will be produced and transported to the moulds in the 250-metre-deep canyon, so two factories are built north of the construction site. From there, concrete is taken in containers by train to the construction site, where cranes take it down to the moulds in the canyon.

The concrete for construction was poured into containers that the trains carried.

WATER AND POWER.ORG

JUNE 1933-FEBRUARY 1935

5 Dam and water towers are cast

In the canyon, workers take delivery of the tonnes of containers. The concrete from them is poured into 200-400-m^3 moulds. By casting in individual blocks, rather than in one large piece, the concrete dries faster. To further accelerate the cooling process, pipes of cold river water run through the moulds. In total, 500,000 buckets of concrete will be emptied before the 221-metre- high dam is completed. Behind the dam, four 132-metre-high towers are built to draw water down to the power plant via the diversion tunnels.

If the dam had been cast in one piece, it would have taken 125 years to cool and set.

BUREAU OF RECLAMATION

drinking water was lukewarm river water that, according to one employee, resembled "coffee with too much cream", while spoilt food poisoned 20 workers.

The reaction from Six Companies was simply that the men were "unused to living under desert conditions".

As a result, nothing was done to remedy the problems and the gruelling work continued as if nothing had happened.

On 7th August 1931, Six Companies ignited the smouldering powder keg itself. When the tunnel workers were told they had to take a pay cut – from five to four dollars a day – a strike broke out. But Crowe was heartless; the workers had to accept the new conditions or leave. When the strikers refused to budge, they were fired. Crowe had to hire a new workforce so construction could continue.

New machine sped up work

In the late summer of 1931, driller Bernard Williams invented a machine – the jumbo – that made a significant impact. The idea came to him one day as he watched a 1916 International lorry removing rocks from the site.

That was when he realised that it could be used to streamline drilling in the tunnels. Williams built two platforms on the lorry bed so that up to 30 men could now drill into the rock at different levels at once. Previously, drillers had only stood on the ground when they were working – which is why the new invention was ▶

able to accelerate the tunnelling process so much.

Once the 30 holes were ready, the truck drove out of the tunnel and so-called 'powdermen' inserted sticks of dynamite into the 3-4-metre-deep holes. After the blast, a crane and a team of clearers drove out and removed the rocks. It was a highly efficient cycle that ran around the clock at each end of the four tunnels. And there was no time for unnecessary breaks.

A young worker realised this when he was accosted by Crowe one day for leaning on his shovel. "What are you waiting for?" the construction boss shouted angrily. "I'm just waiting for 3.30 pm. It's payday," said the young man. When he picked up his pay packet, it contained the agreed salary and his notice of dismissal.

Crowe also fuelled his men's competitive spirit in an attempt to increase the pace. Each group of men was encouraged to dig further than the others during the eight-hour shift. However, the rush led to one team forgetting to check for cracks in the rock wall after a blast one day. When their jumbo was subsequently buried in a rock slide, it was pure luck that everyone escaped with only broken bones and concussions. However, many refused to go to the hospital – because the other drilling teams would overtake them.

Fatal accidents were explained away

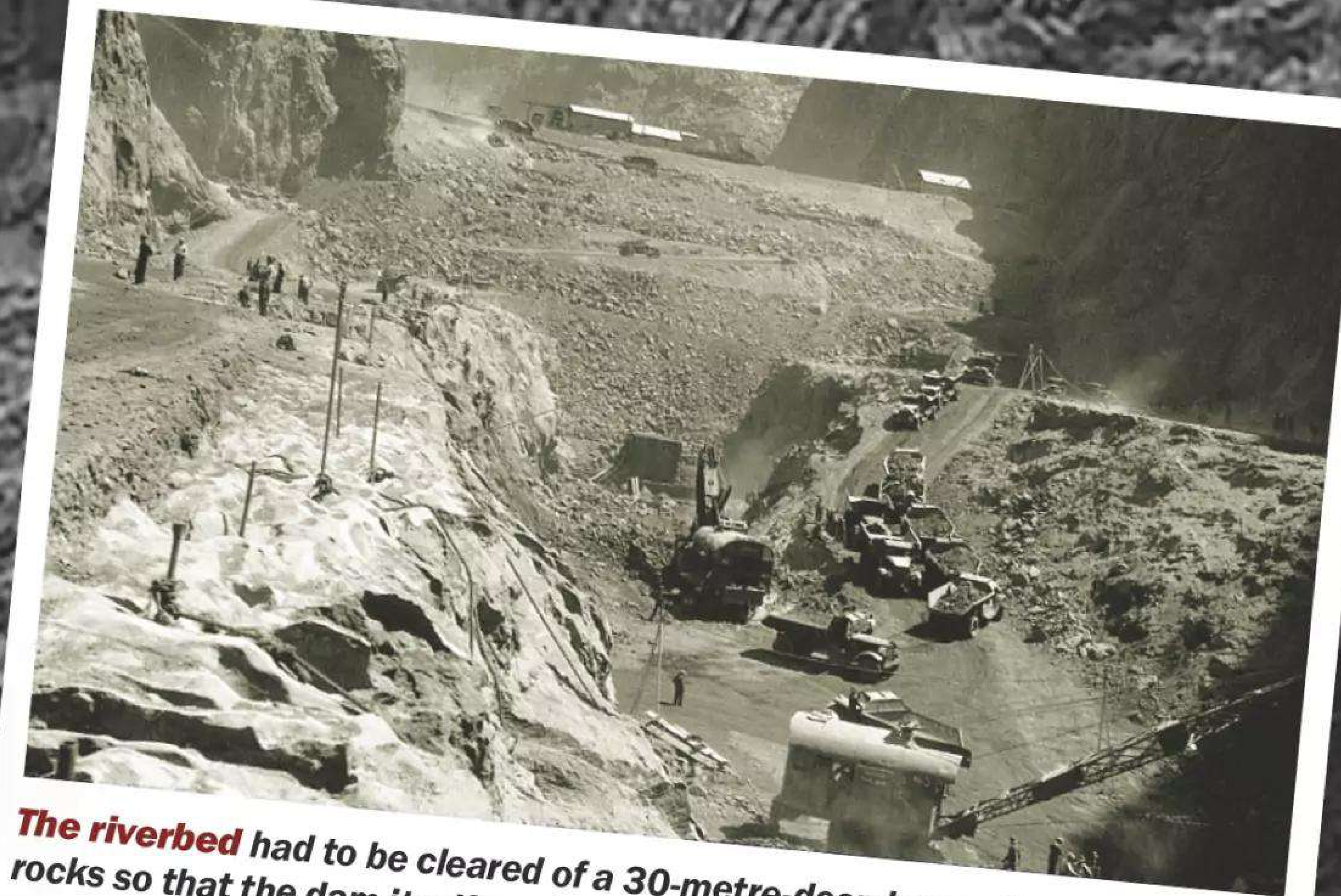
The work progressed quickly, but as the men moved deeper into the rock face, several began to complain of headaches and vomiting. The exhaust fumes from lorries, cranes and generators were creating dangerous levels of carbon monoxide, which claimed 42 lives during the excavation work.

"Our directors would rather take a loss of $100,000 than to hurt one man," Frank Crowe told the press.

However, Six Companies didn't invest in any electric vehicles, which because they wouldn't have emitted exhaust fumes, could have significantly reduced the death toll. The company also avoided paying compensation to the survivors by classifying the poisonings as pneumonia, which was considered a natural cause of death.

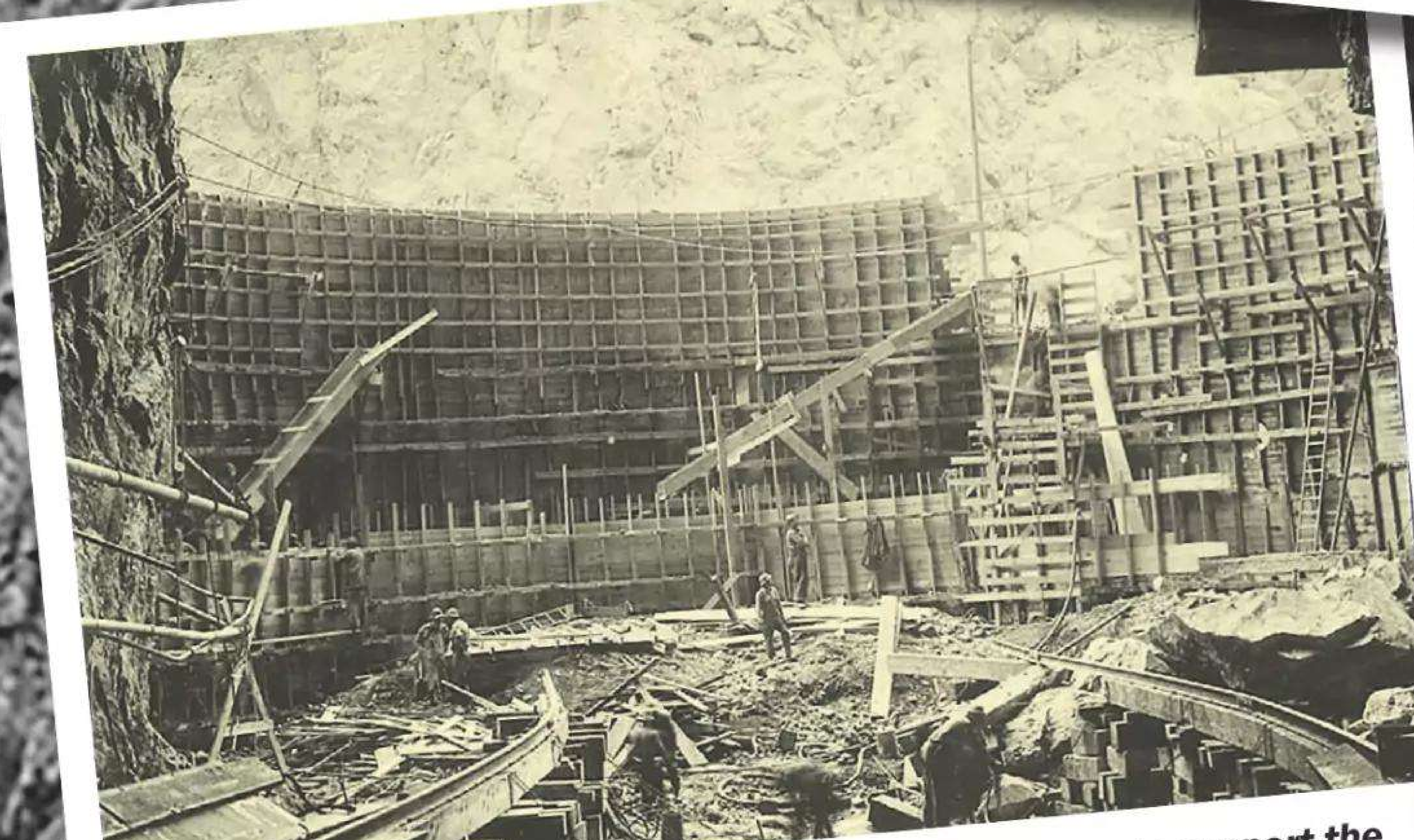
The bosses even set up a PR office to provide the press with positive stories about the working conditions. "Natural air currents" and powerful fans provided "cool, clean and pleasant working conditions", according to one statement.

Later, the newspapers received an explanation from the office: "Physicians ▶



BETTMAN/GETTY IMAGES

The riverbed had to be cleared of a 30-metre-deep layer of silt and fallen rocks so that the dam itself could be built on a solid rock foundation.



RSVLTS.COM

The workers had to build an enormous wooden skeleton to support the many moulds in which the dam would be cast.

RSVLTS.COM

Concrete was lowered in big buckets and emptied into moulds, where it had to be evenly distributed.

Four large tunnels diverted the course of the river during the construction of the dam.
RSVLTS.COM

Model city ensured a sober workforce

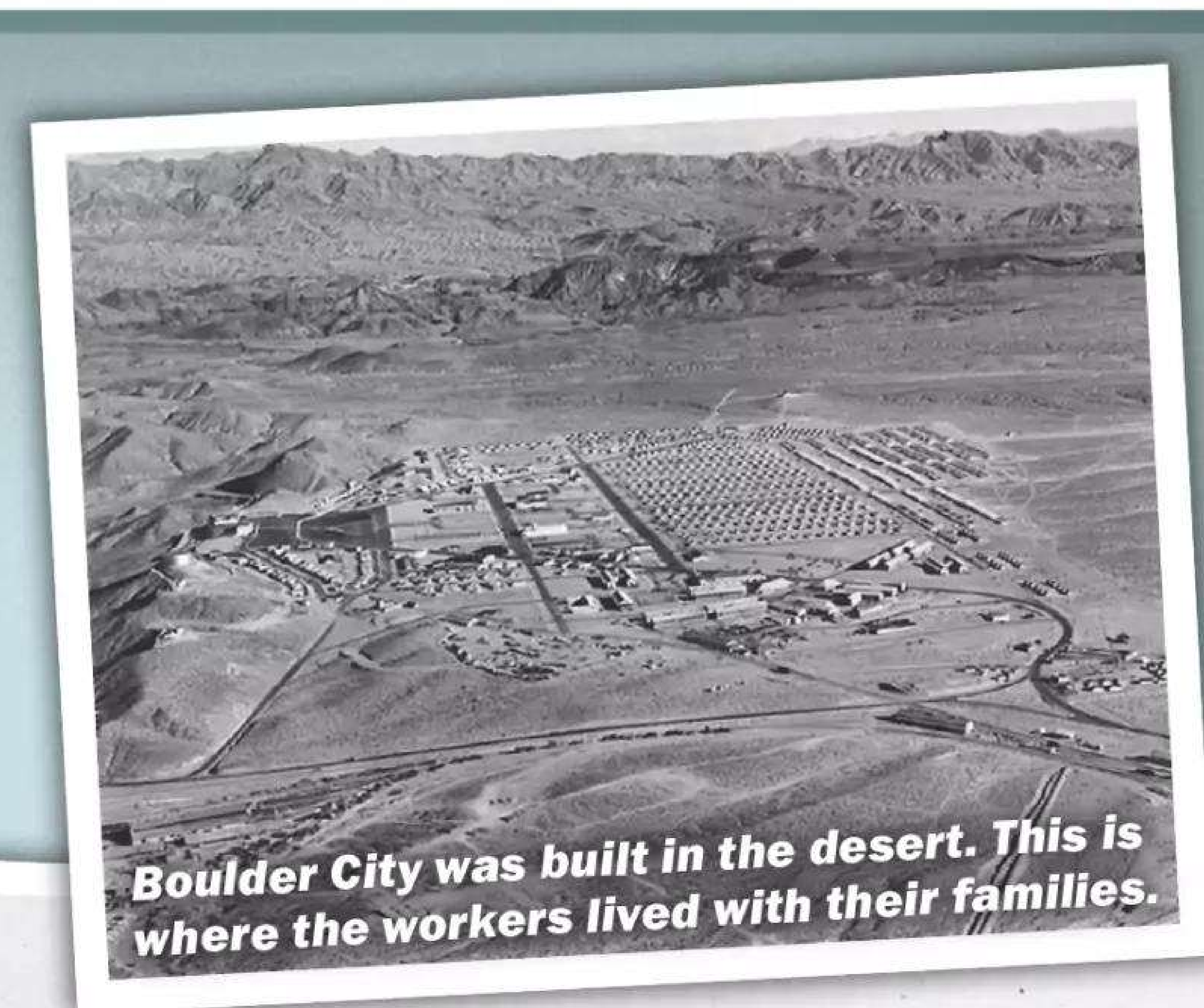
Built in 1931, Boulder City was made to ensure that workers were well rested and fresh every morning when they got up.

Five thousand young men with money in their pockets and easy access to booze, women and casinos will always be a dangerous cocktail.

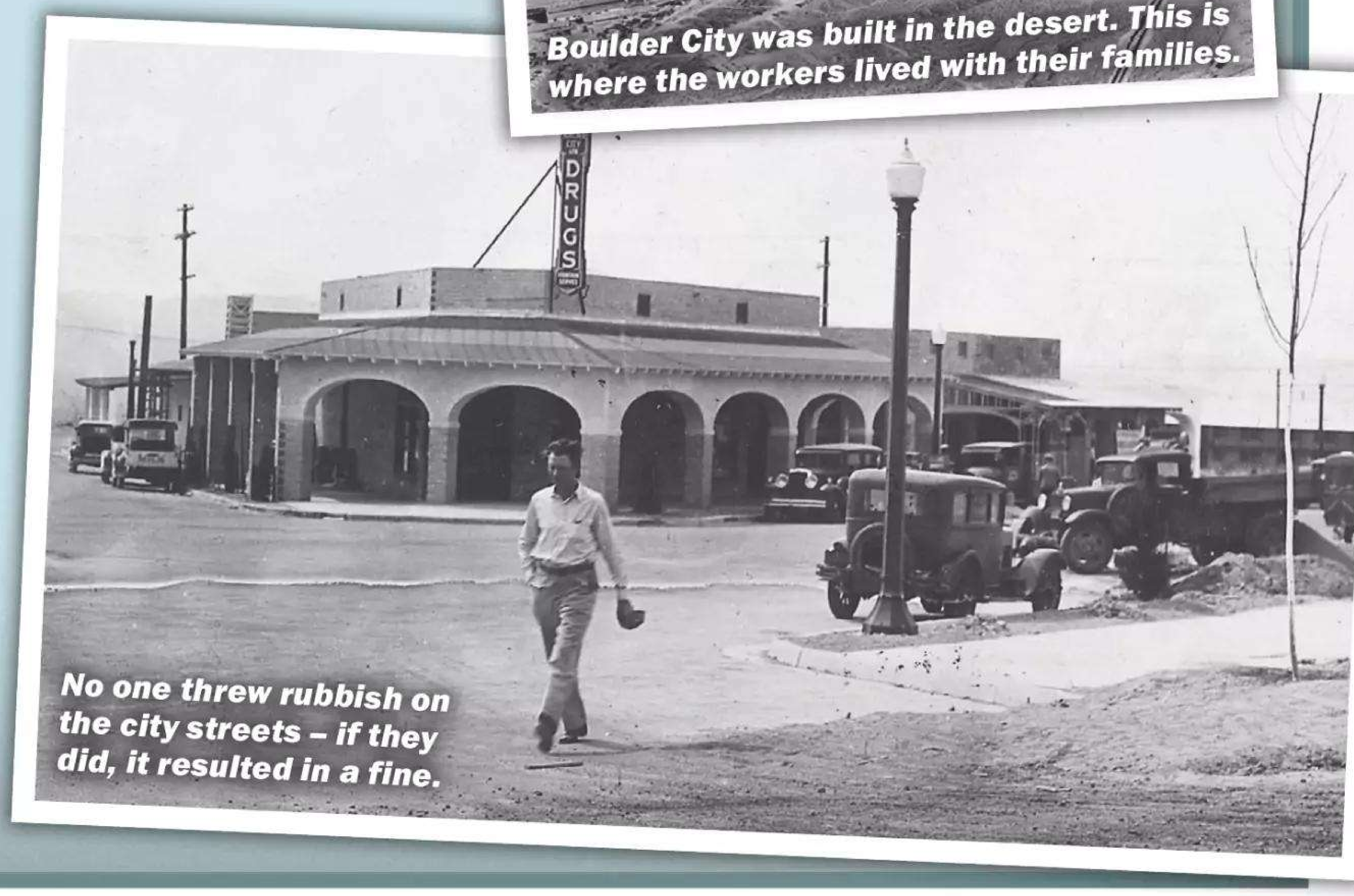
With this in mind, Six Companies chose to build a brand-new city for the many workers. The settlement was named Boulder City and was located just eight kilometres from the work site on the Colorado River.

To avoid any crazy behaviour, the city was run almost like a military camp. The aim was to ensure healthy living conditions so that the workers didn't get sick and the dam was built as quickly as possible.

Neither alcohol nor gambling was allowed. Also, it had to be quiet at night so everyone could sleep. Because of this, children were not allowed to play outside and loud arguments were forbidden. Labourers couldn't complain about the strict rules as trade unions were not allowed in the city.



Boulder City was built in the desert. This is where the workers lived with their families.



No one threw rubbish on the city streets – if they did, it resulted in a fine.

CREATIVE COMMONS

say that many of the cases of pneumonia we have had here this winter were doubtless attributable to a low resistance brought about by drinking bootleg liquor."

By 1932, there were so many carbon monoxide lawsuits pending against Six Companies that it picked up the pace so the tunnels would be completed before a potential judgement could halt work.

However, carbon monoxide poisoning was not the only danger during construction. During 1931 and 1932, a total of 37 workers died in blasting accidents, collisions with vehicles, landslides and falls from great heights.

Trains and cableway carried concrete

Despite the lawsuits, Frank Crowe was already thinking about the next phase of construction. After workers completed the four tunnels, two on each side of the river, the Colorado River was diverted underground in November 1932. They could then begin clearing the dry riverbed of silt and rocks.

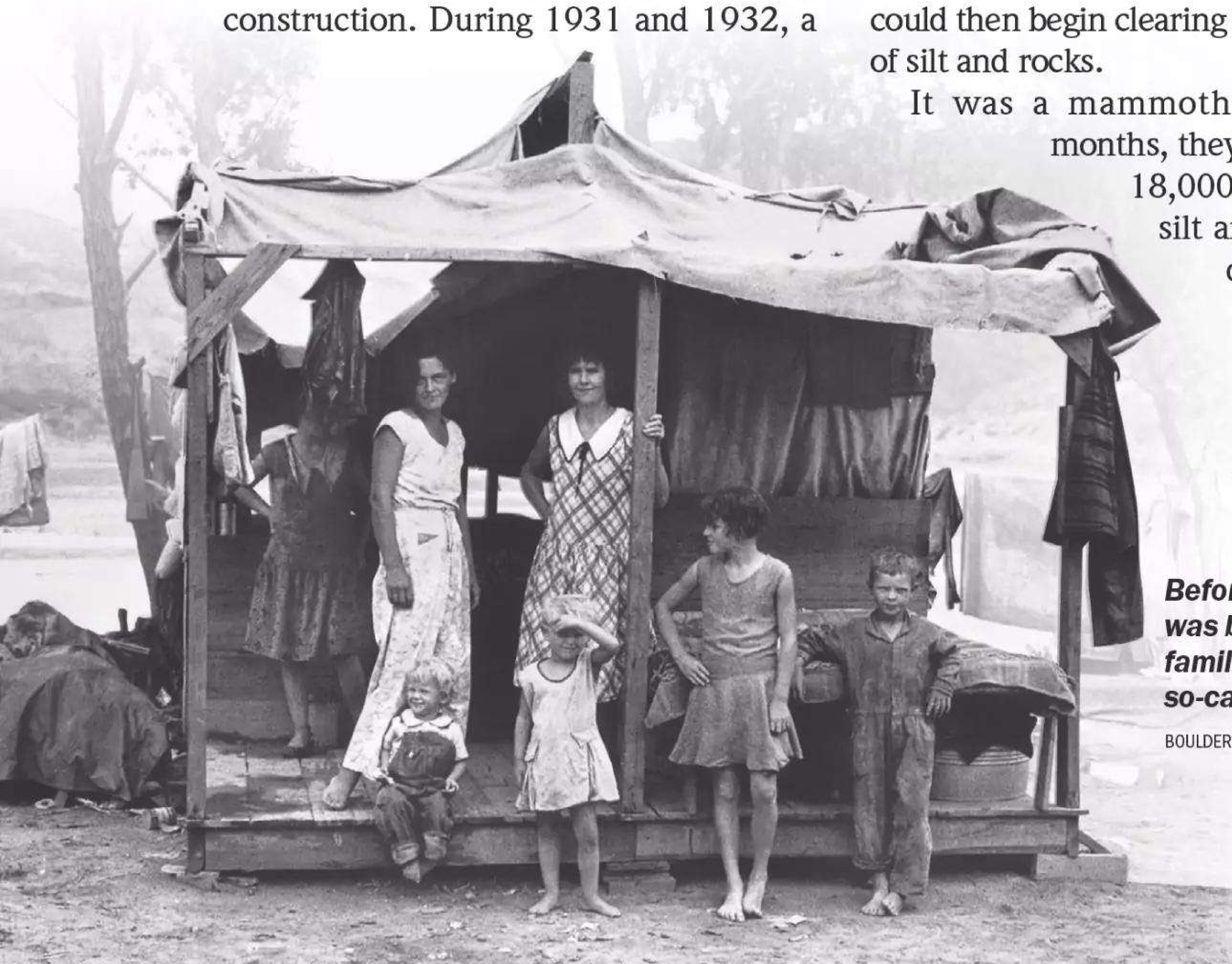
It was a mammoth task. For six months, they removed up to 18,000 cubic metres of silt and gravel every day – the result of thousands of years of river deposits.

While the excavation was underway, Frank Crowe devised an ingenious plan to transport the concrete into the canyon. Nine small locomotives would each haul metal containers containing up to 20 tonnes of concrete to the edge of the Black Canyon. From there, a cableway would lower them the rest of the way down into the depths.

The ten cableways were the most powerful the world had ever seen – one of them could lift 170 tonnes, and the anchor towers were on rails so the cableways could be moved as work progressed. On 6th June 1933, the first bucket of concrete was lowered 250 metres into the depths, where workers emptied its wet load into a 230-square-metres wooden mould. They then set to work shovelling the concrete into place.

Crowe knew he had to cast the dam in smaller blocks; cast in one piece, the concrete would take around 125 years to set. To speed up the process, he invented a system of water pipes to cool the concrete from the inside. The invention was a success, greatly increasing the speed of the work.

However, Crowe's inventions were also dangerous prototypes. At one point,



Before Boulder City was built, many families lived in so-called Ragtown.

BOULDER CITY MUSEUM, W.A. DAVIS

as the cableway was lowering one of the many buckets of concrete down towards the workers, one of the two lines snapped, and the bucket began swinging like a deadly pendulum over the dam. Johnson and Pitts, two workers, didn't have time to move out of the way and were struck with great force by the bucket.

Pitts tumbled 30 metres into the depths before he was crushed against scaffolding with a hollow thud. Johnson, however, was nowhere to be seen. Late that night, he was found on another scaffold – 400 metres away. He had been scooped into the bucket and had only fallen out when its bottom doors opened. Miraculously, Johnson escaped with just bruises and concrete in his eyes. He returned to work the very next day.

Roosevelt would inaugurate dam

In 1934, Six Companies' workforce peaked. Like a finely tuned machine, 5,000 men worked around the clock and the dam grew faster and faster with each passing week.

One journalist was stunned by the efficiency when he visited: "There is no gayety about the scene ... Instead, a kind of surly determination broods over their labour ... [T]the ruthless hiring and firing policy of the Six Companies ... leaves only the supremely efficient on the job."

In June 1933, 19,000 cubic metres of concrete were cast, while in March 1934, 200,000 cubic metres of concrete were lowered into the canyon.

Every day, fresh buckets were sent down and emptied, and the concrete distributed. Block by block, the dam grew – until it rose more than 200 m above the riverbed at the bottom of the canyon.

And finally, on 21st February 1935, the last bucket of concrete was lowered over Black Canyon and emptied into a wooden mould on the dam's 14-metre-wide crest. With this, Frank Crowe had completed the casting process a full two years ahead of the date Congress had demanded. The rush had cost the lives of dozens of men, even though Six Companies received no bonuses for its speed.

But the mega-company saved big money on the early handover; a large proportion of the 5,000 workers could now be let go and wage costs significantly reduced. It also benefited from two years of extra interest on the millions of dollars paid out by the government.

However, President Franklin D Roosevelt had become eager to inaugurate the dam and show it off as a result of his New Deal – his reform programme that would lift tens of thousands out of Depression-era unemployment. As a result, the dam was inaugurated before everything was completed – the hydroelectric power station itself could only produce electricity from October 1936. On 30th September 1935, the canyon fell silent. All of Boulder City was dressed for a party when President Roosevelt's train rolled into the station. From there, a convoy of limousines drove up to a podium at the top of the dam, where the President took his seat.

Thousands of Americans turned out to witness the dedication, and an orchestra from the Boulder City school played.

The boy on the violin was the Godbey family's son, Tommy, who had arrived in the hot, dangerous shanty town with his parents as a toddler. Now his father had a steady job in the city and Erma Godbey was "very proud" of her eldest child.

"This morning I came, I saw, and I was conquered as everyone will be who sees for the first time this great feat of mankind," Roosevelt told the spectators and millions of others listening via radio.

"All these dimensions are superlative. When we behold them it is fitting that we pay tribute to the genius of their designers. We recognise also the energy, resourcefulness and zeal of the builders. But especially we express our gratitude to the thousands of workers who gave brain and brawn to work of construction."

Dam supplied water and power

Up to 21,000 people worked on the massive construction from 1931 to 1935 – and no one in the country could doubt the dam's value to the western United States when it was finally completed.

First and foremost, the hydroelectric plant could supply power to the area's cities – from Las Vegas in the desert to Los Angeles on the Pacific coast. The Hoover Dam also made it possible to control river water, making it easier to avoid flooding in the Imperial Valley, and the dammed water could be used for agriculture along the Colorado River.

The workers behind the construction project came from all over the United States. While 500 of them stayed behind to finish the power plant and maintain the dam, most travelled back to their home states to work in the industries that were recovering from the Depression. Others settled in Las Vegas, which had quadrupled in population during the construction period.

Frank Crowe was the real driving force behind the construction, and although the project had made him wealthy, he wasn't done building dams. "I feel like hell," he said shortly after the inauguration.

"I'm looking for a job and want to go right on building dams."

And so he did. Crowe oversaw the building of three more major dams before retiring in 1944.

Shortly before his death, he was interviewed by *Time Magazine.* Crowe revealed that, despite everything, he had a deep respect for the rank-and-file workers: "If you want to see the fellow who really built this dam, go over to the mess hall. He wears a tin hat, his average age is 31 and he can do things."

Salary was spent on parties in Las Vegas

Every fortnight, the dam workers were paid their wages in Boulder City – typically $56-112 depending on their position. Boulder City was completely dry, so convoys of vehicles travelled the 50 km to the resort town of Las Vegas. For the next 24 hours, the city's 200-metre-long Fremont Street was transformed into a wild party, with the workers spending their money in casinos, bars and brothels.

"By 22.30 things are well underway."

"By 02.00 everyone is drunk ... Rooms are packed to bursting with sweating inebriates fighting for the edge of the gambling tables ... It seems a wild, wild dream of a delirious mind."

"Many a young worker is going to remember Hoover Dam, not as a triumph of engineering skill, but as the place where he contracted venereal disease."

SHUTTERSTOCK

Throughout 1930, 365,000 tonnes of steel and aluminium rose up in the middle of Manhattan. Three thousand intrepid workers created the Empire State Building in record time – the tallest structure the world had yet seen.

WORLD'S EIGHTH

WONDER

SHOT UP IN 242 DAYS

The 381-metre-high Empire State Building held the record as the world's tallest skyscraper until 1970, when the new World Trade Center was inaugurated.

POLFOTO/ULLSTEIN BILD

USA/1929

New York property prices were rising at the same rate as the Wall Street stock market. Everyone wanted to live in Manhattan, and the shortage of space sparked a race to the sky as the rich competed to build the world's tallest skyscraper.

1 MONTH

HEIGHT: 36 METRES

NUMBER OF FLOORS: 12

NEW YORK PUBLIC LIBRARY

BY PELLE STAMPE

The corner of 5th Avenue and 34th Street was packed with curious New Yorkers on that May morning in 1931, most of whom had been walking past regularly for the past year. With their heads tipped back, they had gazed up at the workers balancing on the thin steel skeleton far up in the haze. But that day, the action was on the ground. Thousands of spectators had gathered to witness the official opening of the Empire State Building, America's grandest structure – launched in record time in the midst of the worst economic crisis anyone could remember.

In front of the excited crowd stood a man dressed in a grey suit. Although Al Smith had appeared before large crowds during his time as governor of New York and as a Democratic presidential candidate, that day was special. Three years earlier, he had lost the presidential election to Herbert Hoover – but now the politician stood victorious. He looked proudly up at the 102 floors of the Empire State.

He later explained that he wanted his two grandchildren to cut the ribbon "to symbolise … that this building is to be a monument for generations to come". At 11.29, the two children cut the red silk ribbon with golden scissors – and cheers erupted. Almost at the same time, 330 kilometres south in Washington, US President Herbert Hoover left his cabinet meeting and sat down at a table with an electric switch. As agreed, he flicked the switch at 11.30 and light poured out of the skyscraper's 6,500 windows.

POLFOTO/CORBIS

Politician Al Smith (left) and stock speculator John Raskob (right) were the main men behind the construction.

To the excited cheers of the crowd, Smith took out a silver key and unlocked the building's entrance. The Empire State Building was open. No one doubted that they were witnessing a historic event, and the eighth wonder of the world – as the press had dubbed the soaring building – sent the message that not even the harsh economic climate could break America.

Smith would win the race to the sky

Only a year and a half earlier, the cityscape on 5th Avenue had looked completely different. There, the Waldorf-Astoria had reigned supreme. The luxury

The demolition of the Waldorf-Astoria took almost half a year. The construction of the Empire State Building just eight months.

TOPFOTO

hotel was solidly built and only 26 years old when Al Smith's friend and business partner, stock speculator John Raskob, bought it in 1929.

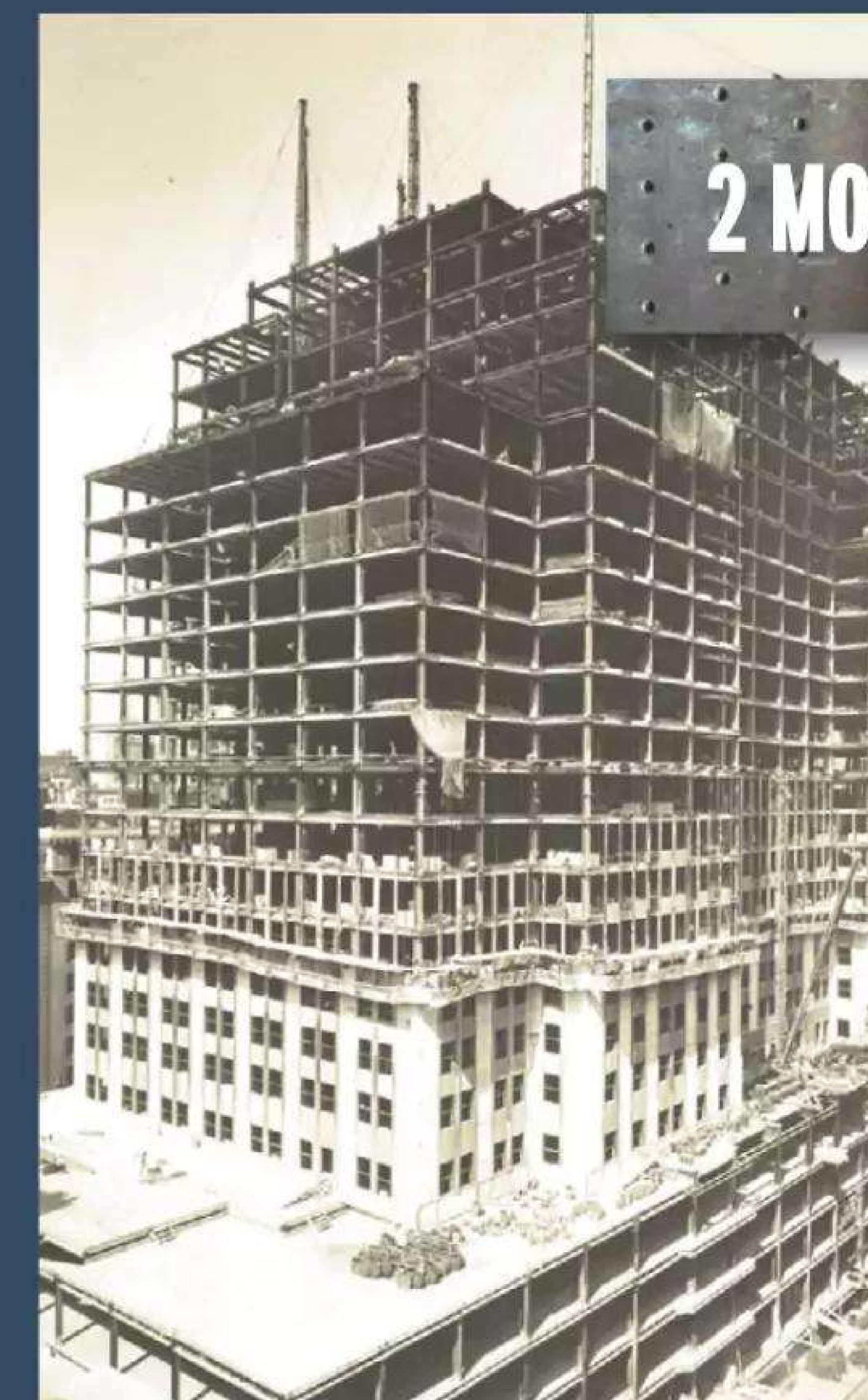
Although neither had built so much as a carport before, Al Smith and John Raskob had big plans for the site in midtown Manhattan. The hotel would be torn down so that Raskob and Smith could win the race to the sky once and for all. They would build the world's tallest and most beautiful skyscraper as a monument to the two men's success – and as a safe investment when the rental income started rolling in. Multimillionaire Raskob financed the project, and politician Smith was the PR man.

Even before the first brick was pulled down at the Waldorf-Astoria, Smith set about publicising the project. On 29th August 1930, he proudly announced at a press conference that he and Raskob would "build a thousand-foot-high, 80-storey office building – the tallest building in the world".

The competition to build New York's tallest skyscraper was fierce, and Smith deliberately understated the height of the new building. The true height of the Empire State Building was to remain secret to ensure no one else built a taller skyscraper. The next day, the *New York Times* announced in huge type on the front page: "Smith to Help Build Highest Skyscraper".

In the following months, journalists filled newspaper pages with stories about the size and beauty of the future skyscraper. Smith announced that the construction would be pioneering. He promised that the Empire State Building would progress at a pace no one thought possible. The skyscraper would be completed 20 months later.

The press revelled in the charismatic Smith's words, and before the ▶



2 MONTHS

HEIGHT: 67 METRES

NUMBER OF FLOORS: 22

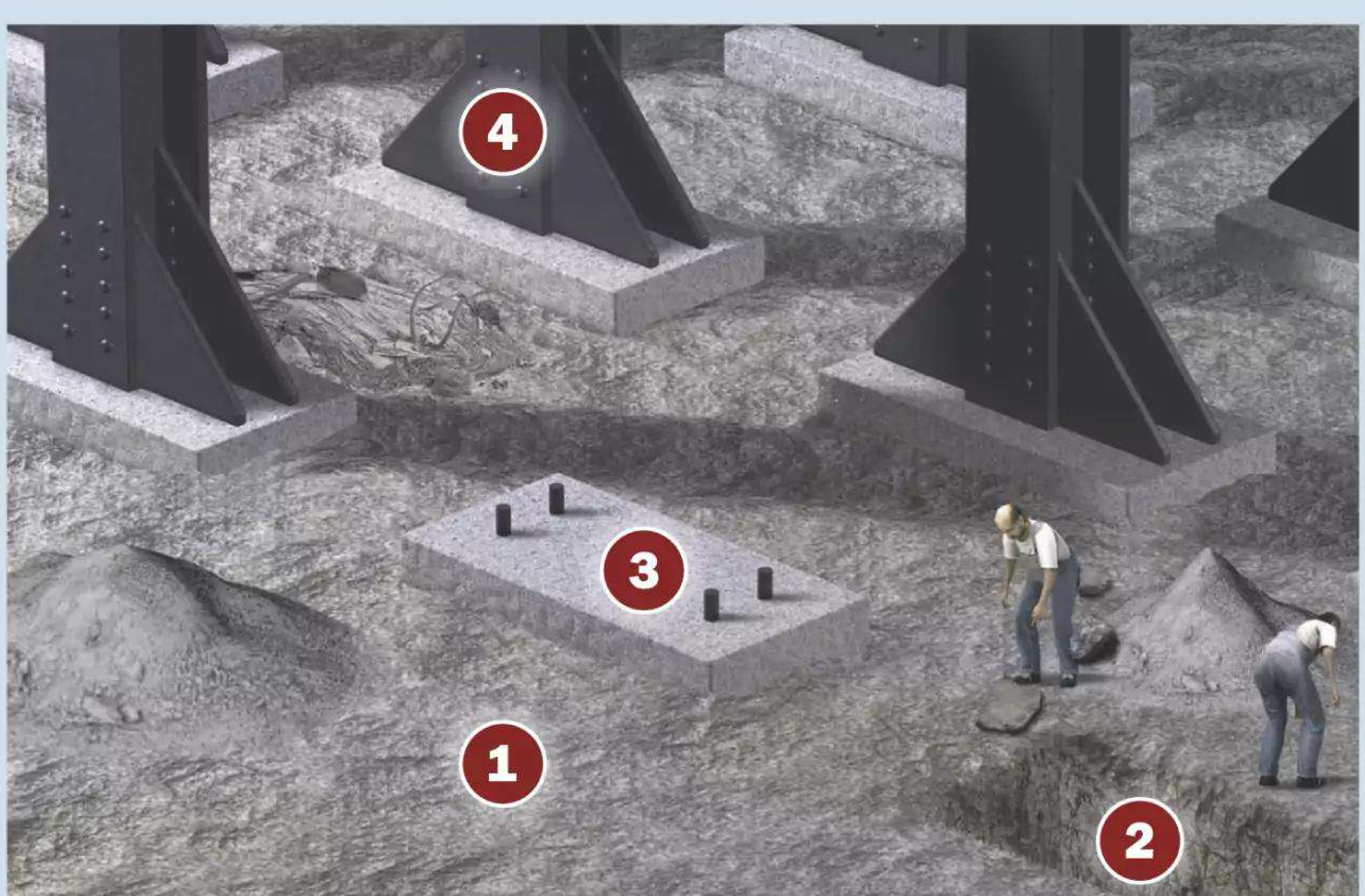
NEW YORK PUBLIC LIBRARY

Empire State stands on 210 legs

The lower steel columns supporting New York's tallest building weigh 44 tonnes. They are attached to steel anchors, cast into concrete foundations. Each of the 210 columns carries 1,738 tonnes of weight.

1 Workers dig **12 metres below street level**. Here they hit the Manhattan granite into which the foundations will be cast.

2 Using dynamite, workers blast **210 holes** in the granite. Each hole is five metres deep, 3 m long and 1.5 m wide to accommodate the foundations.



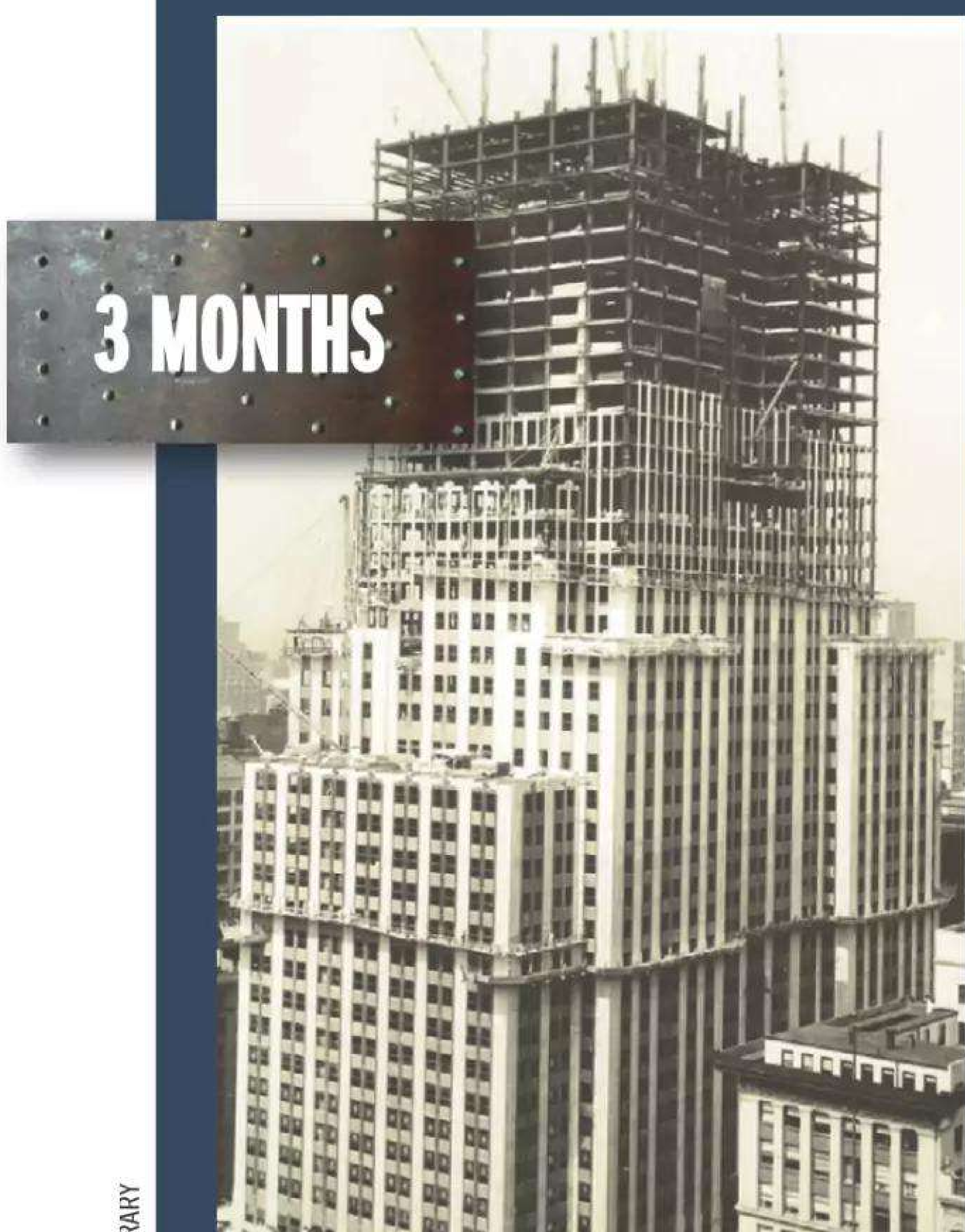
CLAUS LUNAU

3 **Two steel anchors** will be placed in each hole, which will be filled with concrete. The anchors are to hold the lower steel columns in place.

4 **A five-metre-high steel column** is attached to the anchors. To hold the weight of the 365,000-tonne building, the column is 75 cm at each joint.

POLFOTO/TOPFOTO

The steel columns almost formed a boulevard along the site, and became known as the Avenue of Girders.



HEIGHT: 122 METRES

NUMBER OF FLOORS: 40

NEW YORK PUBLIC LIBRARY

groundbreaking ceremony had taken place, journalists had described the Empire State Building as New York's future landmark.

600 men tore down Waldorf-Astoria

Despite all the rhetoric, the project was delayed from the very beginning. New York City Council had banned large demolition machines in Manhattan for the safety of the citizens. The destruction of the Waldorf-Astoria therefore began by hand. Six hundred men used sledgehammers and crowbars to tear the hotel apart brick by brick. Even at night, the floodlit construction site reverberated with hammers and drills.

While the workers toiled around the clock, Al Smith held long meetings with his engineers and contractors about the schedule. To save time, Smith decided to begin excavation for the foundations before the site was completely cleared. So, as soon as the workers removed part of the hotel, the earth and concrete workers moved in. As demolition crews hammered away at the remains of the Waldorf-Astoria, a few metres away, they could see men blasting into the bedrock of Manhattan.

Armed with pneumatic drills, they made large holes in the rock and filled them with dynamite. A worker in a small steam shovel covered the holes with heavy steel mesh mats. These stopped pieces of rock from flying out on to 5th Avenue, but did nothing to stop the infernal noise at the construction site. Neighbours of the site lived for months with the noise of jackhammers and heavy lorries driving up the ramp every four minutes.

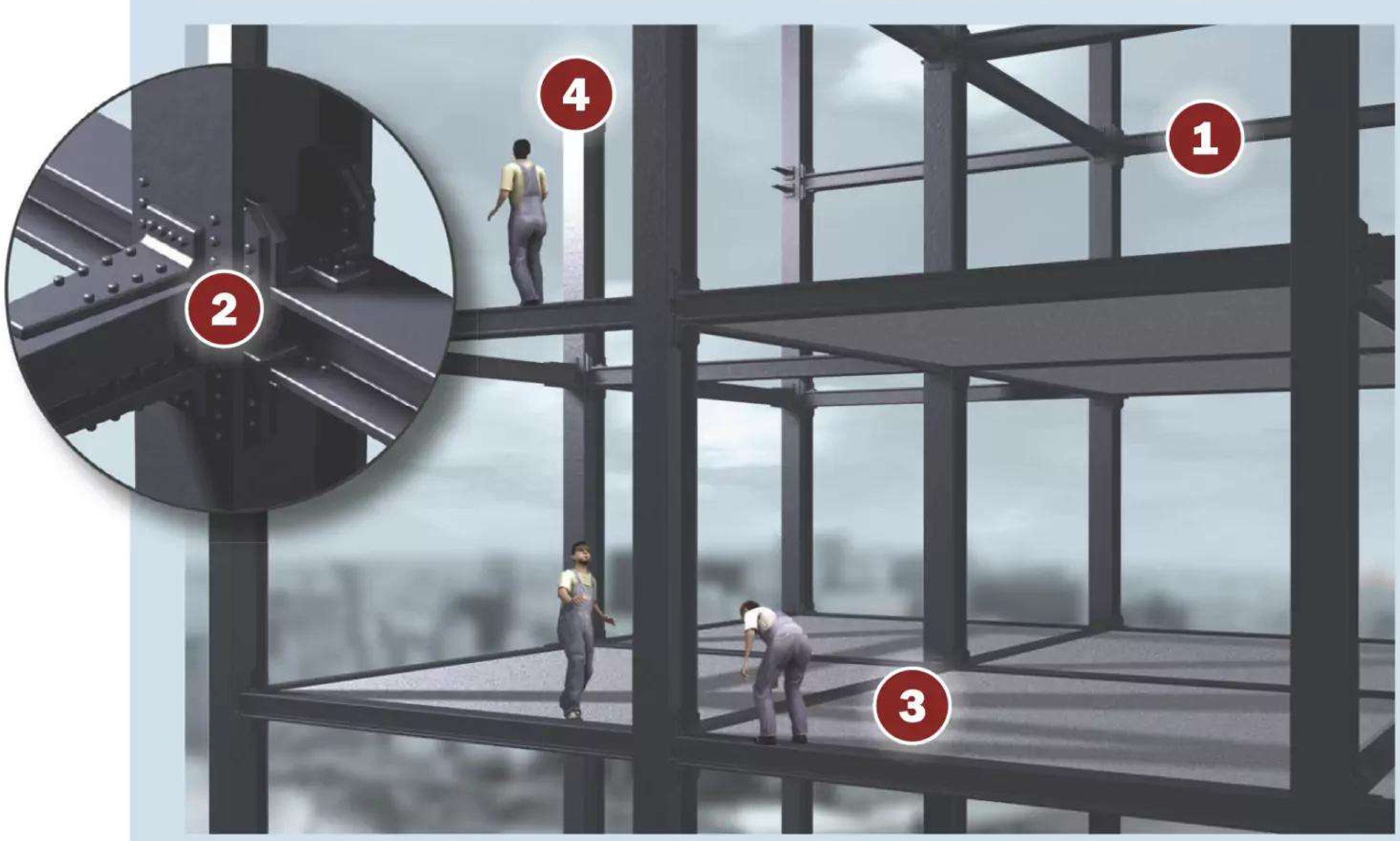
After five months of work, the 28,529th and final load of rubble, granite

Skeleton weighed 60,000 tonnes

The Empire State Building was built as a simple kit. Horizontal and vertical steel girders were connected in a fast-growing skeleton.

1 **Horizontal H-shaped girders** are attached to the vertical columns, like a construction kit. Together they form the steel skeleton of the skyscraper

2 The girders are fastened with **red-hot rivets** that expand when cooled and lock the joints together. Six million rivets hold the skeleton together.



CLAUS LUNAU

3 On top of the girders, carpenters lay wooden planks, then the **cement floor**, then that storey is ready for the bricklayers, electricians and so on.

4 At the same time, the **next storey is going up**. The work is a continuous process, with the building growing by almost three storeys a day.

NEW YORK PUBLIC LIBRARY

Cranes lift the horizontal steel girders and workers balance them in place.

NEW YORK PUBLIC LIBRARY

The rivet teams attach the girders to each other with red-hot rivets.

NEW YORK PUBLIC LIBRARY

Workers enjoy the view from the nearly completed Empire State Building.

and soil was loaded on to a lorry and driven to New York harbour, where it was poured on to a barge, sailed 30 kilometres out into the Atlantic Ocean and dumped into the water.

Building arrived as a kit

By March 1930, the Waldorf-Astoria was gone and workers had dug 12 metres down to bedrock and cast 210 concrete foundations that would support the Empire State Building. Now it was time to move skyward.

Immediately, lorries began rolling building materials into Manhattan. Each part had been labelled by the suppliers with a code describing its location in the building and the number of the crane that would hoist it up. Like a giant construction kit, the materials arrived at the work site. Everything was delivered according to a strict schedule by an endless line of lorries.

Inside the construction site, the work was just as meticulously planned. First, workers attached 210 steel columns to the concrete foundations. They were connected at breakneck speed to hundreds of horizontal steel beams in a grid that grew taller and taller. Eighty hours after the girders left the blast furnaces of the Pennsylvania steel mills, they were set in place in the Empire State Building.

"Things clicked with such precision that once we erected 14.5 half floors in ten working days – steel, concrete, stone and all ... Sometimes we thought of it as a great assembly line – only the assembly line did the moving; the finished product stayed in place," explained one of the architects.

Glowing steel flew through air

Cranes placed the horizontal steel girders on the columns, and they were fixed to each other with steel rivets. The riveters were the most tight-knit team in skyscraper construction. They trained for hours on the ground to find the perfect way to fasten the steel rivets quickly and efficiently. And the teams on the Empire State Building were the best in America.

The so-called 'passer' heated the rivet in a coke forge until it was red hot. Then he picked it up with a metre-long pair of tongs. In one movement, he threw the rivet 25 metres in an underhand throw to the 'catcher' on the steel skeleton, who caught it in a tin can and inserted the hot, soft rivet into a hole. The third worker – the 'bucker-up' – pressed with all his might on one side of the rivet's head, while the 'gunman' used a pneumatic hammer to flatten the pointed end of the rivet. Under the pressure, the rivet cooled, expanded and almost melted into the building. The best rivet teams could fasten over 500 rivets in an eight-hour day – more than one per minute – and their speed determined the pace of construction.

4½ MONTHS

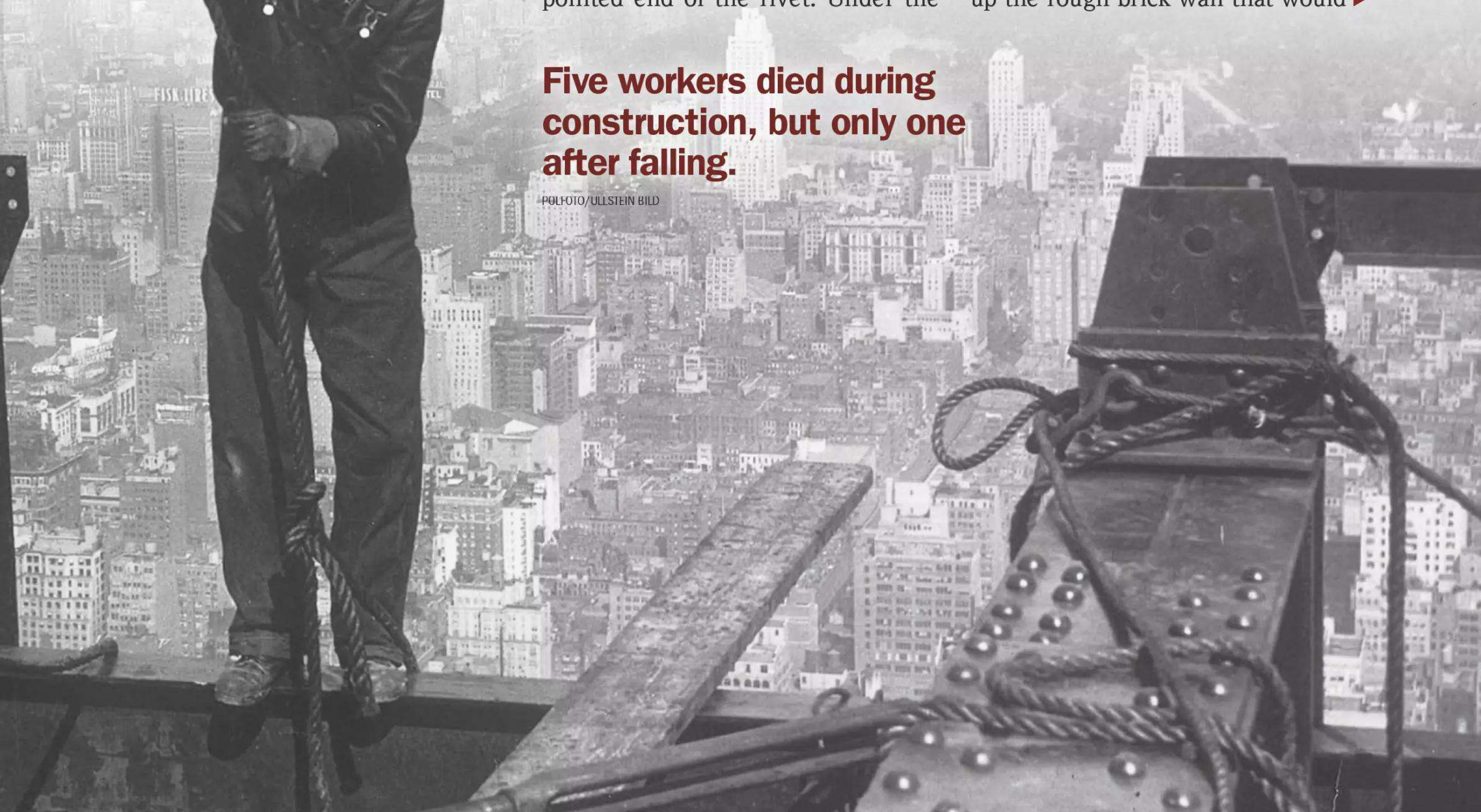
HEIGHT: 168 METRES

NUMBER OF FLOORS: 55

NEW YORK PUBLIC LIBRARY

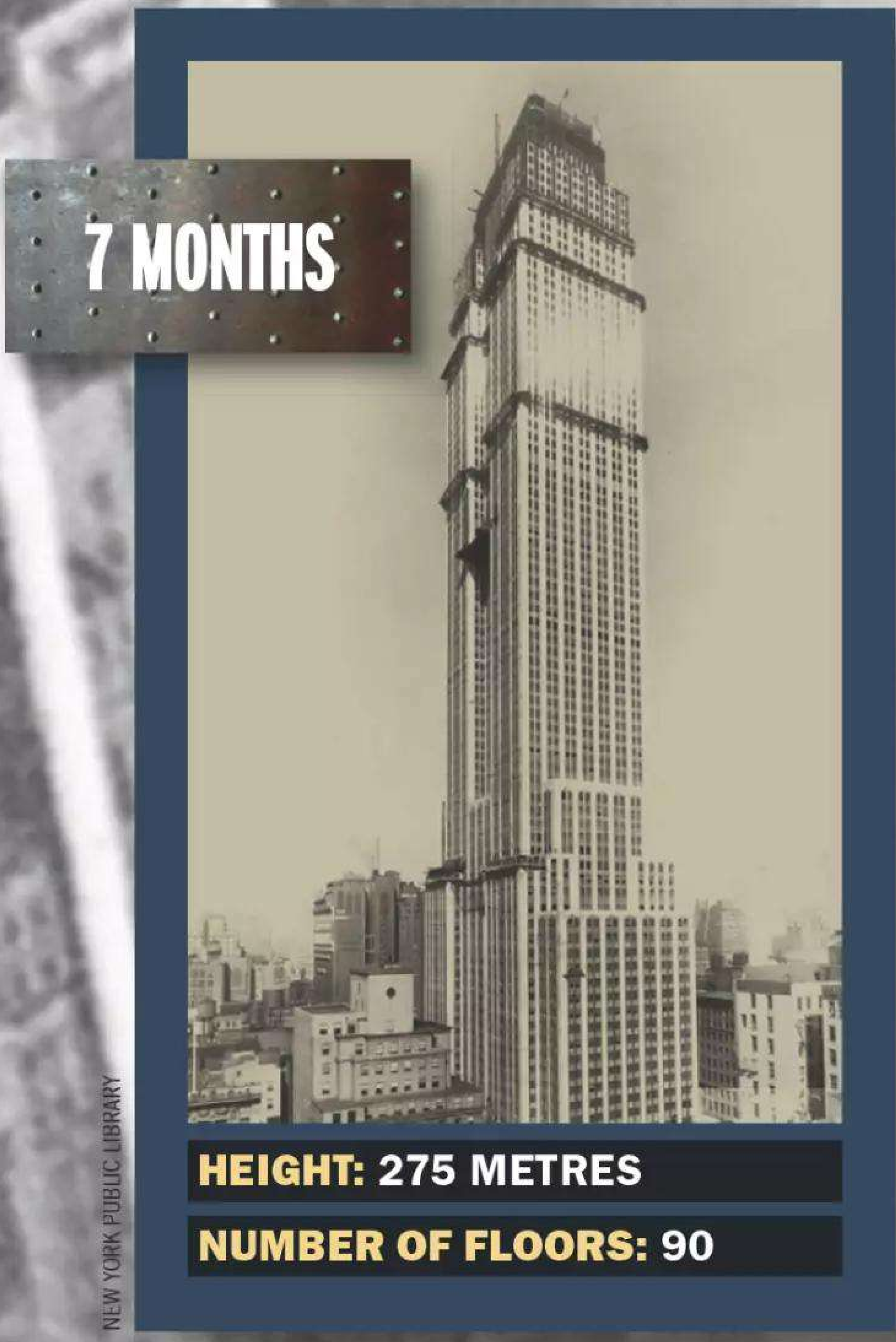
3,000 worked simultaneously

As soon as the steel skeleton had grown a storey, the concrete workers moved in. They cast the floor, and before the concrete was dry, other workers built up the rough brick wall that would ▶



Five workers died during construction, but only one after falling.

POLFOTO/ULLSTEIN BILD



NEW YORK PUBLIC LIBRARY

fireproof the building. Inside, an army of carpenters, electricians and painters moved in.

A total of 3,000 workers were working at the same time in 60 different trades. Work was so fast that carpenters and painters were already laying floors and plastering walls before that storey's ceiling was finished. The biggest problems with keeping to the schedule were not on site, but with the suppliers who couldn't keep up with the accelerated pace.

When an American marble quarry failed to deliver on time, Al Smith immediately cancelled the contract, bought an entire marble quarry in Germany and "took the stuff out by tons", as he said.

Workers became stars of New York

The rapidly growing skyscraper caused a stir among New Yorkers. Since those halcyon days when Smith had proudly announced his plans, the worst economic downturn of the century had hit the US. The Wall Street Crash of 1929 had plunged the world economy into depression, and unemployment was rampant. For poor New Yorkers, the construction became welcome free entertainment. They watched in awe as the steelworkers crawled death-defyingly around the skeleton – literally on the edge of the abyss, hundreds of metres up. The workers balanced tonnes of steel beams in place with millimetre precision: "Like little spiders they toiled, spinning a fabric of steel against the sky," wrote the *New Yorker.* Despite the speed of construction, the workers were almost spared serious accidents.

To prevent fatigue causing workers to make mistakes and have accidents, their working day was cut from the normal ten hours to eight, and the working week shortened to five days. A safety net to catch workers and falling material was stretched under the floors the workers were on. The net also protected Al Smith and John Raskob from having to pay large compensation payments to injured workers or passers-by on the street who were hit by falling debris.

In total, five workers died during construction, only one of whom fell from scaffolding. The second was run over by a lorry while clearing the Waldorf-Astoria; a third died while blasting the granite foundation; the fourth fell down a lift shaft; and the fifth was hit by a working lift when he stuck his head into the shaft to look for the lift.

If Smith and Raskob saved money by not needing to hire replacement workers, they invested heavily in the well-being of their men; the two of them secured the best and fastest labour by paying workers at the Empire State Building up to $15 a day – four times more than at other New York construction sites.

Sitting with a fabulous view of the metropolis, the feted workers ate lunch from one of the building's five cafeterias on the third, ninth, 24th, 47th and 64th floors. At the same time, boys ran around the steel skeleton delivering water to the workers. The cost of this arrangement alone was $25,000, but in return, the workers avoided the long trips down for water that could have delayed construction.

112 km of pipes in building

The steel skeleton and facade of the Empire State Building was completed on 13th November 1930. In 242 days, workers had bricked, riveted and cast 102 floors over 381 metres.

Work on the interior lasted another four months. Among other things, electricians installed 762 kilometres of electrical cables and plumbers

The 48-metre-high mast was to serve as an anchorage for airships. The gusting winds so high up made the plan impossible.

POLFOTO/TOPFOTO

laid 112 kilometres of pipes into the skyscraper.

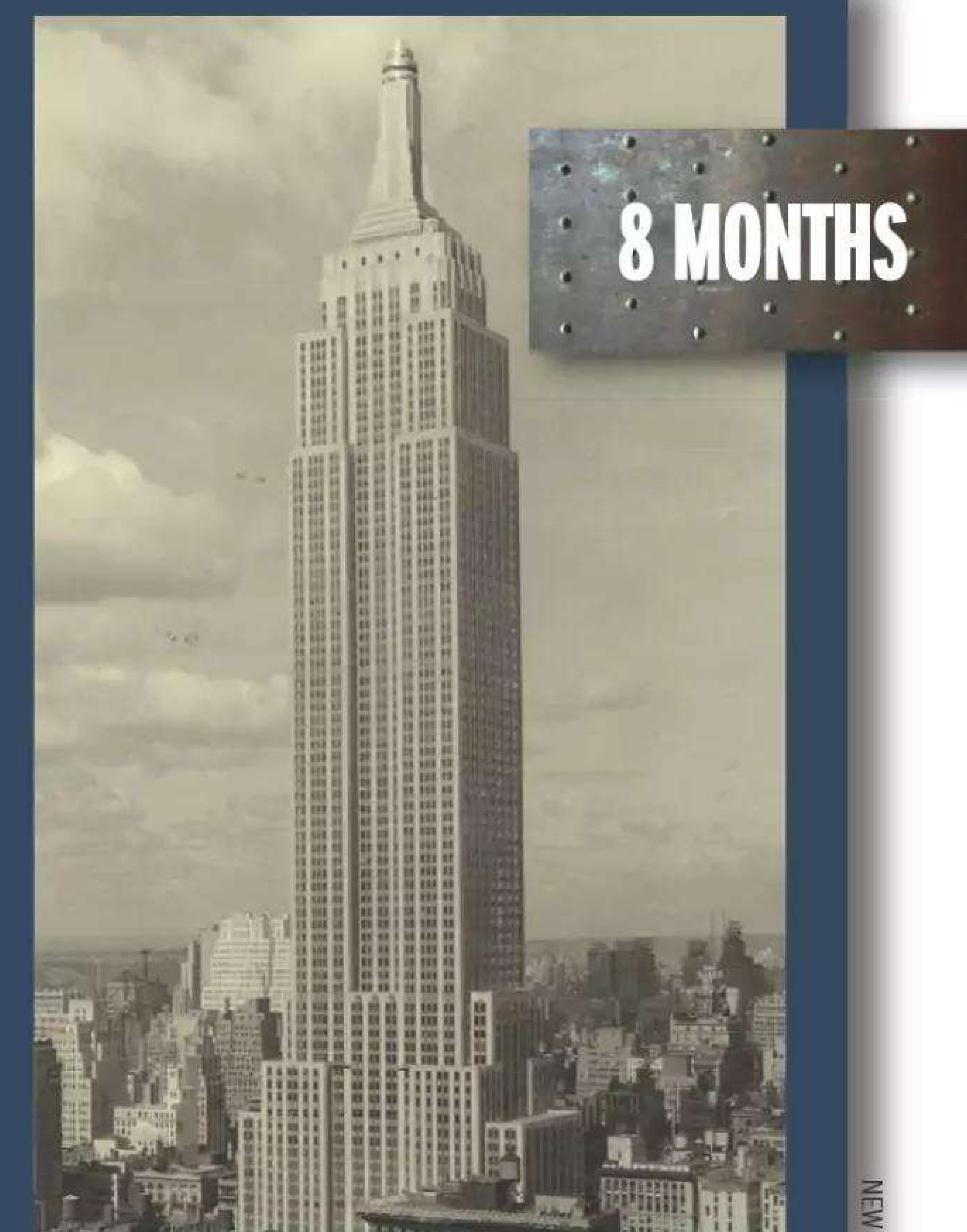
And then, on 1st May 1931, a proud Al Smith formally opened the 365,000-tonne skyscraper. During the ceremony, he received a telegram from one of the building's architects, William Lamb, who had left New York by ship the day before: "One day out at sea and I can still see the building," it read.

Empty State Building close to grief

The jubilant ceremony was forgotten in a matter of months as the Depression set in. Unemployment had exploded and the majority of the 3,000 workers had to join the dole queue after the construction, with no chance of finding a new job.

The crisis also hit Smith and Raskob. Renting out the offices in the Empire State Building was supposed to be a gold mine, but no one could afford to move into the new building. The $41 million (about $600 million today) building stood empty, and New Yorkers sarcastically dubbed it the Empty State Building. Al Smith kept the building's lights burning around the clock so the building wouldn't look empty, and soon people began to fill the huge marble lobby. New Yorkers flocked to ride the lift up to the observation deck. In 1931 alone, nearly a million people pulled a dollar out of their pocket to take the 70-second lift journey up to the 86th floor and look out over Manhattan.

The revenue from the observation deck saved Raskob and Smith's skyscraper project from bankruptcy, and the Empire State Building came to be a visible symbol of the fact that New York had become the world's leading metropolis.



HEIGHT: 381 M WITH MAST

NUMBER OF FLOORS: 102

NEW YORK PUBLIC LIBRARY

Facade consists of limestone and aluminium

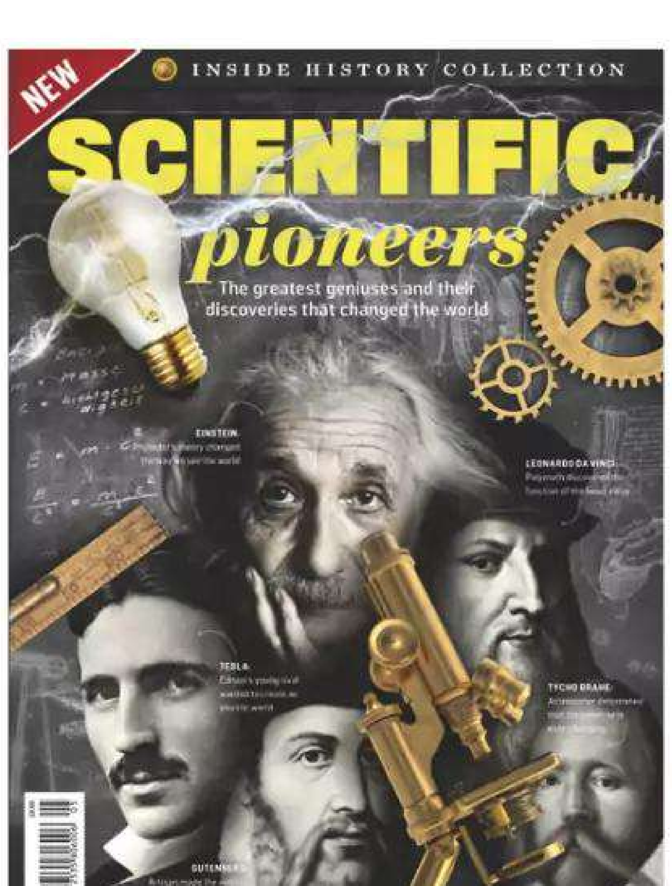
Bricklayers insulated and fireproofed the Empire State Building's 102 floors with brick walls. On the outside, workers created the skyscraper's distinctive look using limestone and aluminium panels.

CLAUS LUNAU

NEW YORK PUBLIC LIBRARY

Limestone was sourced from the best limestone quarry in the US near Bloomingdale, Indiana, 1,100 km away.

Bricklayers use more than **10 million bricks** 1 to build the interior walls of the Empire State Building. On the outside of the bricks, workers attach rectangular **nickel bars** 2 that hold the **aluminium panels** 3 and **60,000 m² of limestone slabs** 4 in place. Finally, workers install the Empire State Building's **6,500 red window frames** 5 between the aluminium panels.



SCIENTIFIC PIONEERS

PUBLISHING DIRECTOR: Elisabeth Halmø
EDITOR-IN-CHIEF: Ann Qvist
PRODUCTION: Eva L. Strandmose
TRANSLATORS: Nick Peers, Katharine Davies, Karen Levell, Toni Baxter
COVER DESIGN: Sidse Lange

INSIDE HISTORY COLLECTION IS PUBLISHED BY:
Bonnier Publications International AS,
PB 543, 1411 Kolbotn, Norway.

MARKETING/DISTRIBUTION UK:
Marketforce (UK) Ltd,
121-141 Westbourne Terrace,
London W2 6QA, UK
0330 390 6464 | Hello@Marketforce.co.uk

LICENSING AND SYNDICATION:
Regina Erak – regina.erak@globalworks.co.uk
Tel: +44 (0)7753 811622

ISSN: 2535-8065
PRINTED BY: Poligrafijas Grupa Mukusala, Ltd.

BONNIER
Publications International

NORDIC SWAN ECOLABEL
Printed matter
3041 0876

SCIENTIFIC *pioneers*

Embark on an adventurous journey of scientific discovery following in the footsteps of alchemists, astronomers, physicists, inventors and other great geniuses. Their thirst for knowledge and search for answers has driven the world forward whether studying the solar system, understanding the elements or charting the history of human evolution. In this issue, read about these and other milestones that have helped us in the fight against disease, led to the construction of record-breaking buildings and inspired our continued search for solutions to the great mysteries of the universe.

History
BONNIER
Publications International